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XIX

TERTIARY AND QUATERNARY HISTORY OF THE PETALUMA, POINT REYES AND SANTA ROSA QUADRANGLES

BY

ROY E. DICKERSON

Honorary Curator, Department of Invertebrate Paleontology

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Introduction and Acknowledgments

The geology of the southern half of California and that of the Sierra Nevada has been largely elucidated because the occurrence of those great sources of California's mineral wealth, Oil and Gold. Owing to the lack of such an economic inducement, geological research and mapping in the northern half of the Coast Ranges has been largely neglected. The writer became interested through work in the southern half of the state in certain problems whose solution required detailed mapping in the northern half. Some interesting and unexpected results were obtained through an extension of the work of Professor Lawson in the San Francisco Quadrangle, and that of Dr. Weaver in the Napa Quadrangle, east of the area studied. The excellent topographic maps of the Petaluma and Santa Rosa quadrangles were available during most of the time the writer was engaged in this research. The Point Reyes Quadrangle was not available during the field work. It is hoped that the rapid publication of suitable topographic maps will lead to more work in this much neglected field.

The writer is aware of the incompleteness and many deficiencies of this work, but it was thought best to present the results obtained at this time so that they may be available for use by others.

For helpful criticism, the writer is greatly indebted to Professors Andrew C. Lawson, John C. Merriam, Ruliff S. Holway, Bruce Clark, and Chester Stock of the University of California; Professor James Perrin Smith of Stanford University; Professor Earl L. Packard of the University of Oregon; Dr. W. S. W. Kew of the U. S. Geological Survey; and to Mr. John B. Kerr, Geologist, General Petroleum Company, who assisted in the field work during the summer of 1916. The writer is also under great obligations to Mr. H. C. Bundy, who prepared the geological sections, and to Mr. L. L. Stewart who drew the manuscript copy of the geological maps. The California Academy of Sciences provided the facilities for this work and the paleontological collections upon which it is based are deposited in that institution.

The mapping of the Petaluma Quadrangle and the southern half of the Santa Rosa Quadrangle is detailed as respects the Tertiary formations, but no attempt was made to differentiate the formations within the Franciscan group. The northern quarter of the Point Reyes Quadrangle is reconnaissance mapping only, as the topographic sheet was not available in the field. A small amount of detailed mapping was done upon the Pleistocene formations in Tomales Bay. The writer is indebted to Mr. F. M. Anderson[1] for the excellent mapping of the rest of this quadrangle. Owing to different scales, some of the contact lines are not exact; nevertheless, the map shows the approximate distribution of the formations correctly.

Outline of Results

The area under discussion is immediately north of the San Francisco Bay Region, or it may be regarded as a northern part of this terrain. It is cut on the west by Tomales Bay which was determined by that notable feature, the San Andreas Rift. Long continued faulting in this zone has caused a separation of the Point Reyes Triangle, a northern extension of Professor Lawson's[2] Montara Block from the eastern shore of Tomales Bay, the mainland. One of the conclusions of this paper is that this condition is an old one and that the Triangle and the mainland have been subjected to different sets of movements during the geologic past as well as the present. The exact nature of these motions is not entirely understood, but some progress has been made in discovering their character. The Pleistocene formations which are exposed in the headlands on the eastern side of Tomales Bay prove, both by their lithology and fauna, that this long inlet existed during their deposition and that earthquake movements were prevalent then. The absence of these sediments from the western shores of the bay and the presence of fine terraces in the shales and sandstones of the Point Reyes Peninsula, indicate that the Triangle moved independently of the mainland, as successive titan steps (marine terraces) were cut during periods of standstill. These steps do not correspond to those of the mainland nor to the slotted-

[1] Anderson, F. M., The Geology of Point Reyes Peninsula, Univ. Calif. Publ., Bull. Dept. Geol., vol. 2, No. 5, 1903.

[2] Lawson, A. C., San Francisco Folio, No. 193, U. S. Geological Survey, p. 16, 1914.

in blocks of Pleistocene in the Tomales Bay trench of the San Andreas Rift. The mainland, the San Francisco-Marin and Berkeley Hills, blocks of Lawson, as will be shown later, has been subjected to a peculiar hinge-like movement by rotation along an axis situated somewhere in the area east of Santa Rosa and Petaluma valleys. This mainland-block's uptilted edge is exposed along the shores of Tomales Bay and the Pacific Ocean. Apparently warping or differential tilting has also affected it. The peculiar type of stream drainage within the area affected by these fault blocks, so well described by Holway,[3] is a result of this type of movement. The northern extension of the Hayward Rift Zone was recognized on the western flanks of Sonoma Mountain and proofs of recent activity were established through the recognition of fault sag ponds, fault shelves, minor drainage modifications, and similar features. The occurrence of estuarine fossils of upper Miocene age in the clays and sands of the Petaluma formation fixes the age of a freshwater fauna which is also found in these beds. A study of the Petaluma formation adds an interesting chapter to the history of this region during upper San Pablo time and indicates that the San Pablo sea did not extend to the northward in this region. A revision of the stratigraphy of the beds in Sonoma Mountain which yielded the remains of the Pliocene horse, *Neohipparion gidleyi* Merriam, indicates that this horizon is in the Sonoma group. The Sonoma group is correlated with the marine Merced group by excellent stratigraphy in this region. Neohipparion is a form which occurs in the Orinda formation of the Berkeley Hills and the Etchegoin of the San Joaquin Valley. Upon this basis and stratigraphic studies, the Merced group is broadly correlated with the Sonoma group, Pinole tuff, Orinda of the Berkeley Hills and Etchegoin formation of the Great Valley.

The investigation of the Pleistocene deposits of Tomales Bay led to the recognition of two distinct formations of this period. Small estuarine faunas were obtained from the upper beds of the Tomales formation, while the lower beds of the Millerton formation yielded several species which are now found only in the latitude of San Diego. In other words,

[3] Holway, R. S., Physiographically unfinished entrances to San Francisco Bay, Univ. Calif. Publ., Geog., vol. 1, No. 3, pp. 90-95, 1914.

the faunas in both formations are sub-tropical and indicate warm interglacial epochs. Just what time interval is represented by the unconformity which separates these two formations is very difficult to evaluate as these beds are in the immediate line of faulting along the San Andreas Rift where great changes are possible within a very limited space of geologic time, but the writer believes that this was an important break. In both beds, well preserved cones of the Monterey pine *(Pinus radiata)* were found. This species does not at present range north of San Mateo County, it being replaced in the present day flora of this region by *Pinus muricata*. Thus it is evident that both the faunas and the floras of these beds indicate warmer climates during the Pleistocene interglacial epochs than at the present time in these latitudes.

Review of the Literature

This region was cursorily examined by Whitney[4] who noted that marine sandstones rested upon the metamorphics (Franciscan) and he referred these sandstones to the Miocene. We now know that they are Pliocene, the Merced formation. Gabb[5] described *Metula remondii* from the sandstones of this Pliocene formation at San Antonio Estero near the town of Tomales, and several other fossils from the vicinity of Mark West Creek from beds of the same age. Lawson,[6] in the Geomorphogeny of the Coast of California, gives the first detailed information about this area. He recognized that the terraces of Point Reyes Peninsula were due to wave erosion, described briefly the great fault which conditions Tomales and Bolinas bays, and perceived that the last movement, recognized in this vicinity, the subsidence which gave rise to San Francisco Bay, had also affected Point Reyes Peninsula. "Even more significant of the recency of the depression are the flooded streams which end at the sand beach of Drakes Bay. These are called Drakes Estero on the Coast Survey Chart. They are finger-like inlets which are very clearly flooded stream canyons, representing a drainage convergent towards the south.

[4] Whitney, J. D., Geology of California, vol. 1, pp. 81-85, 1865.
[5] Gabb, Wm., Geological Survey of California; Palæontology, vol. 2, pp. 3, 72, pl. I, fig. 5, 1869.
[6] Lawson, A. C., Univ. of Calif., Publ. Dept. Geol., vol. 1, No. 8, pp. 245-246, 264-265, and 268-269, 1894.

These canyons have effected the dissection of a plateau which is a marine wave-cut terrace, representing one of the later stages of the epeirogenic uplift of the coast." Concerning the possibility of a Pliocene peneplain Professor Lawson says: "It may, perhaps, be well to state here that in those portions of the coast which once served as areas of Pliocene sedimentation, as in the vicinity of the Bay of San Francisco, much of the geomorphic character was evolved in pre-Pliocene time, and had simply been revealed and modified by the stripping off of the Pliocene accumulations." The accuracy of this conclusion will be better appreciated after the evidence for this surface has been described around Petaluma and Freestone. At these places the conditions are essentially in accord with Lawson's statement. Lawson suggested that Petaluma Valley was once occupied by the Russian River. His statement is as follows: "Associated with the subsidence which flooded the Bay of San Francisco, there were probably other deformations of the crust which seem to have had an important influence on the drainage. The most notable instance of this kind is the shifting of the divides of the hydrographic basin of the Russian River. This stream once clearly flowed through Petaluma Valley to the main drainage outlet at the Golden Gate. A low divide in the middle of the old valley now causes the drainage to flow westward at right angles to its former southerly course, and seek the coast by the present transverse route. The change in the drainage may be due to stream capture or to crustal warping. The latter is most probably the cause; but the problem has not yet been studied sufficiently." The writer is not in agreement with this statement in its entirety, but warping, as Lawson points out, is one of the controlling influences in the development of the physiography of this country. Lawson also discusses this region in the San Francisco Folio. Mr. F. M. Anderson[7] mapped and described the Point Reyes Quadrangle and his excellent mapping is used in this publition with but slight alteration. These changes are the addition of the Pleistocene formations in Tomales Bay region and reconnaissance mapping of Merced strata around To-

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[7] Anderson, F. M., Geology of Point Reyes Peninsula, Univ. Calif. Publ., Bull. Dept. Geol., vol. 2, No. 5, 1903.

males. Osmont[8] constructed a reconnaissance cross-section across this general region. This paper was found very suggestive, although the writer is in disagreement with several portions of the text. The San Pablo (?) of Osmont which was described as being in the vicinity of Freestone is beyond doubt Merced, as fossils found at Freestone prove. The area east of Petaluma which he regards as Orinda (?) is the Petaluma formation of upper Miocene age described in this paper. The teeth of the Pliocene horse, *Neohipparion gidleyi* Merriam, were reported by Osmont as coming from the San Pablo (?) formation beneath the lavas of Sonoma Mountain, whereas they were found in strata which are interbedded with these lavas of the Sonoma group. The synclinal structure of Petaluma Valley as interpreted by Osmont does not appear to be the explanation of this topographic feature. The Sonoma tuff of Osmont does not prove to be as accurate a horizon marker as he thought since there are several strata of tuff in Sonoma Mountain which are separated from one another by lava flows. The writer is indebted to Osmont for his careful study of the igneous rocks of the region. Professor J. C. Merriam[9] described the teeth of *Neohipparion gidleyi* to which reference was made in a brief paper concerning the occurrence of these interesting remains. He states "that they probably came from a stratum just below the coal seam at a mine on the Lawler Ranch, six miles east of Petaluma, California. The formation has been doubtfully referred to the San Pablo Miocene, but may represent a later period." Dr. G. K. Gilbert[10] in the California Earthquake Commission's Report gives an excellent description of the fault features shown along the San Andreas Rift in the vicinity of Olema and Tomales Bay. He also discusses the modifications in the drainage caused or controlled by rifting. A trace of the fault of 1906 is given in the atlas of this report. This same publication contains collateral biologic articles by Dr. C. A. Kofoid[11] and Dr. Wm. E.

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[8] Osmont, Vance, A Geological Section of the Coast Ranges North of the Bay of San Francisco, Univ. Calif. Publ., Bull. Dept. Geol., vol. 4, No. 3, pp. 39-87, 1904.

[9] Merriam, J. C., New Species of the Hipparion Group from the Pacific Coast and Great Basin Provinces of North America, Univ. Calif., Publ. Dept. Geol., vol. 9, No. 1, pp. 1-8, 1915.

[10] Gilbert, G. K., Report of the State Earthquake Investigation Commission, vol. 1, part 1, p. 66, Publ. Carnegie Institution of Washington, 1908.

[11] Kofoid, C. A., Idem, p. 89.

Ritter[12]. Professor R. S. Holway[13] of the University of California has published two papers upon the physiography of this region and its environs, "The Russian River, a Characteristic Stream of the California Coast Ranges," and "Physiographically unfinished Entrances to San Francisco Bay." What little the writer has to add to these problems is but slight modification of Professor Holway's principal thesis.

Concluding the paper upon the Russian River, Professor Holway makes the following statement: "In attempting to summarize the history of the Russian River in its various parts the limitations noted in the introduction, namely, the lack of maps showing the topography and the areal geology, necessarily limits definiteness of statement in any conclusions stated. In briefly recapitulating the conclusions already offered in the discussion of the various sections, some comment will be made concerning their probability or concerning possible alternative hypotheses.

The lower river is termed antecedent and is considered the remnant of a former consequent coast stream which has held its position despite the slow uplift. It is possible that much of it flowed over the soft recent deposits and by the removal of that series has been let down upon older rocks in which it now flows. Technically such a history may justify the use of the term "superimposed", but in no place is the present river out of harmony with the minor topography in the way that the Middle River is in various places. The antecedent condition of the Lower River fully accounts for leaving the open Santa Rosa Valley and crossing the western highland in a canyon. The Lower River is termed antecedent, as a sufficient explanation. If superposition of the river upon the Merced series ever existed, it has not resulted in any relations that are not explained by its more antecedent character. The Middle River in its peculiar cutting off of the point of a ridge in Alexander Valley, in its course through Fitch Mountain, and in incising its channel on the slope of Santa Rosa Valley, exhibits the characteristics of a superimposed river,—a conclusion justified by the existence within

[12] Ritter, Wm. E., Idem, p. 88.

[13] Holway, R. S., Univ. Calif. Publ., Geog. Dept., vol. 1, No. 1, p. 38, 1913; Univ. Calif. Publ., Geog. Dept., vol. 1, No. 3, 1914.

the area of patches of the softer and later series through which the Middle River has cut down to its present position."

The occurrence of Merced fossils at Plantation a few miles north of the mouth of the Russian River, also at Freestone, a short distance south of the Lower River, indicates to the writer that the intervening area was once covered by Merced sandstones and shales and probably a thin veneer of marine Pleistocene terrace material as well. Subsequent erosion has removed these incoherent materials along the present course of Russian River and has left for present topography the old Miocene or early Pliocene peneplain cut in Franciscan rocks upon which the sands and gravels of the Merced sea were deposited. In brief, the Lower River as well as the Middle River is superimposed. Holway described accurately the peculiar relations of Walker and San Antonio creeks in the monograph, "The Physiographically Unfinished Entrances of San Francisco Bay" and his hypothesis that they were once one stream which drained to Tomales Bay is confirmed by these studies. The writer thinks that the tilting of the mainland block is the cause of this "broken-backed" stream and that the waters of the middle and upper portions of the Pleistocene Walker Creek were spilled out by way of one of the headwater tributaries when the tilting was sufficient to overcome the grade of the stream. This will be discussed further in the latter portion of this paper.

Geology

The oldest rocks in this general region are limestone, quartzite, and schists of possible Paleozoic age which occur only in Point Reyes Peninsula. These rocks are remnants of the roof of a great granitic batholith of probable Mesozoic age and they occur as inclusions in the granite of the Point Reyes Peninsula. Rocks of the Franciscan group of possible Jurassic age are restricted to the east side of the San Andreas Rift and Tomales Bay. For many miles east of Tomales Bay, the Franciscan is either the surficial rock or it forms a base upon which the later rocks rest. Another interesting group from a distributional point of view is the Monterey of Middle or Lower Miocene age. This, like the granites and limestones, is restricted to the Point Reyes Triangle and no indications of its presence in any other portion of the area occur on the surface, but one of the characteristic products from the shale phase of this group—petroleum—may have been supplied to the overlying sands in the Sonoma group. Eastward in Carneros Creek, beyond the area under discussion, rocks of this age are again found. It seems probable that this formation was once continuous over the area between Sonoma Mountain and Tomales Bay, but was eroded during Upper Miocene and the interval between Miocene and Pliocene time. A formation of Upper Miocene age, here described as the Petaluma formation consists chiefly of lacustrine deposits, and indicates that the upper Miocene Sea which occupied the present site of San Pablo Bay Region did not extend in this region to the northwest. The Merced group of Pliocene age and its correlative, the Sonoma group, are well exemplified in this region and their stratigraphic and faunal relations are clearly demonstrated. Two interesting formations of marine Pleistocene were differentiated on the eastern shores of Tomales Bay. Such, in brief are the formations recognized within this field.

Limestone of Mesozoic or Paleozoic Age

An area of coarse-grained marble occurs in connection with the granitic rocks of the Point Reyes Peninsula on the eastern slope of Inverness Ridge. This marble which was carefully studied by F. M. Anderson is very similar to the "Santa Cruz limestone" of the Santa Cruz Mountains and that of Montara Mountain. The geologic relations are the same in all three cases. The limestone mass was intruded by the granitic magma and those portions of the batholithic roof which dropped into the melting pot were preserved for our inspection. Granitic rocks largely surround the Inverness Ridge limestone area.

Granitic Rocks of Probable Mesozoic Age

The granitic rocks of this region are restricted to the Point Reyes Triangle and are not found on the eastern side of Tomales Bay, as Anderson pointed out in his paper describing this area. Anderson's[14] description in part is as

[14] Anderson, F. M., The Geology of Point Reyes Peninsula, Univ. Calif. Publ., Bull. Dept. Geol., vol. 2, No. 5, p. 124, 1903.

follows: "In the field the granites of Point Reyes appear as moderately coarse-grained, light gray rocks showing rough and rounded surfaces where they are firm, though usually they are much decomposed. Where erosion is not rapid the rocks are decayed, often to a depth of a dozen feet or more, but on the summits where harder phases protrude, and in the deep ravines where the erosion is greatest, and along the shore the rocks are firmer and often more angular. All of them, where favorably exposed, are seen to be greatly shattered and broken, and testify to the large amount of disturbances they have undergone. The rock is mostly unfit for quarrying purposes on this account, since it is not easy to find many blocks of any considerable size. These granites are to be classified as normal biotite granites. Quartz is in only moderate proportions, and both orthoclase and plagioclase feldspars are present. As to the quantity of biotite present, there is considerable variation. Basic segregations are common, in which there is no quartz and little feldspar, while on the other hand there are phases containing but little biotite. Hornblende is not abundant."

Franciscan Group, Jurassic (?)

Rocks of this group are restricted to the mainland in contrast with the granitic rocks of the Triangle. The San Andreas Rift Zone sharply separates these terrains, but unfortunately at no place are they in close contact. There can be no doubt that they were separated by ancient movements along the San Andreas Rift. This ancient fault line seems to lie on the western side of Tomales Bay, as the Franciscan occurs beneath the Pleistocene deposits on Hog Island and Tom's Point, both of which are located about two-thirds of the way across Tomales Bay from its eastern shore. The eastern face of Inverness Ridge must of necessity be interpreted as a much eroded fault scarp. The Franciscan group occupies the greatest area of any in this field and it underlies most of the region now covered by the Merced formation. Island-like masses such as Meachims Hill, appear through the veneer of Pliocene sediments in many places. In other words, the peneplain upon which the Merced was deposited was cut in Franciscan rocks, and many monadnocks were left standing above the general surface of this notable feature. In and around Petaluma this same relationship is seen in several places. No attempt was made to separate this group in the mapping, but nearly all its characteristic rocks occur within this area. Since this terrain is merely an extension of the Franciscan which Lawson[15] mapped in detail in the Tamalpais Quadrangle, of the San Francisco Folio, the reader is referred to this work for details. Chert, glaucophane schist, garnet schist, actinolite schist, sandstone and igneous rocks associated with this group,—serpentine and basalt—were recognized in this region. A conglomeratic limestone was also noted a few miles south of Petaluma. This limestone seemed to be a beach deposit and although it appeared as if it might be fossiliferous, no samples were found which contain unmistakable organic remains. This deposit will be described in detail under Economic Notes.

No attempt was made to work out the structure within the Franciscan, but only the nature of the contacts between this group and the Tertiary rocks of the region was studied. In general, as noted above, the Franciscan forms the basement upon which the marine sediments of the Merced group were laid down and upon which the lavas, volcanic ashes and breccias of the Sonoma group were outpoured. The Franciscan is, however, in fault contact with the Petaluma formation of upper Miocene age in the vicinity of Lakeville. This fault, whose trace is indicated upon the geologic map of the Petaluma Quadrangle, is apparently an ancient one, as the lavas of the Sonoma group rest upon the Franciscan south of Tolay Creek as well as upon the Petaluma formation immediately north of that stream at about the same elevation. Evidently, no pronounced movements have taken place along this line of weakness since the close of the Miocene. For convenience this line of weakness will be referred to as the Tolay Fault.

Monterey Group, Middle Miocene

This group is excellently exposed in the Point Reyes Peninsula where it is the most important formation from an areal viewpoint. Anderson's mapping and description of this terrain have been borrowed from his excellent paper in order that the reader may grasp certain problems which are only

[15] Lawson, A. C., U. S. Geological Folio, No. 193.

solved by considering the distribution of the groups in the general field. Mr. Anderson's description is as follows:

> Miocene Sediments.—The Miocene series consists of three members, the upper two of which are not distinctly separated. The lower member is a dark heavy, conglomerate, in which the pebbles and stones range from one-half inch to more than one foot in diameter. The second member is a thin-bedded, cream-colored sandstone that passes quite gradually into the upper member, the special features of which will be described later. It is the white Miocene shale of the Monterey series, well known in the Coast Ranges. This series is essentially similar at all the points at which a complete section is to be seen. At the summit of Whittenberg Hill a series of the Miocene sediments, some hundreds of feet in thickness, have conglomeratic beds at their base, with a thickness of eight or ten feet, containing pebbles of granitic and crystalline limestone.

Concerning the shales of Whittenberg Hill, Anderson remarks that

> . . . Nothing of great importance has been discovered on the peninsula, not already known from other regions, and their petrography would be merely a repetition of what has been said before. In texture they vary from a tolerably granular, sandy phase to what might be called flinty. In Bear Valley and west of Whittenberg Hill, the compact, somewhat vitreous and banded phase is more frequent, though this appears to be an areal rather than a stratigraphical variation. Such portions of the shale are both less porous and less bituminous than the more granular portions. West of Drake's Estero the shales are sandy and the amount of bituminous matter is very much greater than in the more compact portions. This is commonly seen in the fetid character of the water rising from them.

Rocks of this group are not found in the mainland portion of this area. In the region west of Petaluma it is probable that these rocks were totally removed during the erosion interval at the close of the Miocene or early Pliocene as the marine Merced rests directly upon the Franciscan in this vicinity.

It seems entirely probable that rocks of this group once extended over this area as its characteristic shales and sandstones are well exposed in the headwaters of Carneros Creek in the Napa Quadrangle about 20 miles east of Petaluma. At this place a fair fauna representing the Arca montereyana zone has been obtained. This group may underlie a portion of Sonoma Mountain as a product which is yielded by its shales—petroleum—is found in a sandstone which is a member of the Sonoma group. A fault of moderate throw has exposed this sandstone and underlying and overlying basalt in a creek bed about 5 miles northeast of Petaluma, one-quarter mile north 20° W. of Mountain School in the Santa Rosa Quadrangle. The sandstone in places is thoroughly impregnated with oil and droplets of oil were found in the vesicular cavities of the overlying basalt. There are no other indications of the Monterey group beneath Sonoma Mountain that were found but it seems very probable that the basalts and tuffs of the Sonoma group are underlain by the shales of the Monterey group. The clays and sandstones of the Petaluma formation probably intervene in many localities. The Monterey group may underlie the Petaluma formation in the region southeast of the Mountain School. What would preserve this group from erosion here while it was entirely removed from the whole area only 4 miles west across Petaluma Valley? As has been pointed out above, the Tolay fault has not been active since late Miocene or early Pliocene but during this time the eastern or downthrown block may have been so lowered beneath the general base level of that time that it was in this manner preserved from the general destruction which the western block suffered. Whether this area around the Mountain School has any economic oil possibilities is problematic, although the writer is not prepared to condemn the area absolutely, yet the uncertainty of a source of oil is very liable to make this region a pecarious one for experimenting.

Petaluma Formation, Upper Miocene

This formation is confined to the northeast corner of the Petaluma Quadrangle and the adjoining southeast corner of the Santa Rosa Quadrangle. Stratigraphically, it is unconformably overlain by the Sonoma group of volcanics and their associated members on its eastern boundary while its western limit in the Petaluma Quadrangle is marked by the Tolay fault which separates it from the Franciscan in this vicinity. On the northwest, the incoherent sands of the Merced formation mantle it in the vicinity of Penn Grove. Lithologically this formation is characterized by the great abundance of clays, but only in certain stream canyons does one obtain opportunity to observe them. Elsewhere they have readily weathered into a thick, heavy soil. The different lithologic facies are typically exposed along the Lakeville-Sonoma road between Lakeville School and Eureka School and vicinity. In this area, while no continuous section occurs, we find several fair exposures sufficient to enable us to distinguish this formation from the Merced group which occurs in the near vicinity. A fine-grained, light-brown sandstone occurs at Eureka School at the cross roads. The bedding in this massive sandstone makes the structure obscure, but the approximate strike is N. 60° W., and dip 25° N. A coarser brown sandstone and its associated conglomerates which are free from basaltic or andesitic pebbles or other fragments of the Sonoma group are found along the road at intervals of about a mile southwest of Eureka School. The absence of these rocks from the Petaluma formation, and their general presence in the sandstone of the Merced group, enable one to discriminate these formations in the field. The pebbles in these conglomerates consist of chert, quartz, schist and sandstone fragments and most of them have been derived from the Franciscan group. Along the road which runs northwesterly from Eureka School in the bottom of the stream just west of the road, green clay with thin strata of interbedded limestone occurs. This clay is well stratified but does not exhibit characteristic shale structure in most exposures. Limestone is frequently present in the form of small nodular masses and is very argillaceous. Resting upon this green clay is a tan sandstone containing green grains. These beds have a strike of N. 55° W., and dip of 20° S., while just a short distance on the north side of the road reverse dips were found in the same material in the small gulches entering the major stream. The green and light gray clays are well exposed in a tributary of Tolay Creek about 2 miles southeast of Eureka School. These deposits are characteristically lacustrine. That this is true, is amply proved by the presence of brackish and freshwater fossils in them in the extension of this formation to the northwest. Certain other lithologic variations are best observed here as well. A sandstone which occurs one-quarter mile east of Waugh School, Santa Rosa Quadrangle, is interbedded with clays which yield a stiff adobe soil. This sandstone contains obscure fossils—plant remains—and it is lighter in color than the prevailing sandstone of the Merced group. Small chunks of light colored clay ranging from a quarter inch to an inch in diameter are embedded in the clayey sandstone matrix. In the stream canyons east of Waugh School many excellent sections of this formation may be seen. The great abundance of petrified wood which is found in the sandstones of this formation is very noteworthy. In one place this material formed a stratum from 8 inches to a foot in thickness.

FAUNA

Two interesting faunas occur in the Petaluma formation: the one, a brackish water and the other, a freshwater fauna. The estuarine facies was recognized on upper Lichau Creek where *Corbicula californica* (Gabb) was collected and at California Academy of Sciences Locality No. 415. About 2.1 miles N. 26° E. from Elmore School in canyon and two-fifths mile southeast of Mountain School road, clay shale and soft, fossiliferous sandstone are found interbedded. The overlying igneous rock near the contact is basalt and agglomerate.

The best preserved specimens occur at California Academy of Sciences Locality No. 415, but only two species, *Corbicula californica* (Gabb) and *Bittium rodeoensis* (Clark), were found here. These two forms, however, are also found associated in the uppermost portion of the San Pablo formation, in the Pinole syncline, on the shores of Carquinez Strait and San Pablo Bay, showing that the identity of these two horizons is highly probable. In other words, the Petaluma formation is a freshwater and brackish water phase of the marine San Pablo formation of upper Miocene age. The stratigraphic relations also reinforce this correlation as both the San Pablo and the Petaluma formations are unconformably below the Sonoma group and its equivalent, the Pinole tuff. Probably stratigraphically above this horizon containing the brackish-water fauna is another set of beds whose clays have yielded a very finely preserved collection of freshwater shells. California Academy of Sciences Locality 417, where these shells were obtained, is in Haggin Creek, about 200 feet below the bridge on clay beds which are overlain by conglomerate one mile southeast of Penn Grove, Santa Rosa Quadrangle. The strata dip 12° S. W. and have a strike of

N. 60° W. The fossils belong to the genera *Sphærium, Pisidium, Planorbis, Lymnæa* and *Physa,* and form an assembly of species very similar to that found in the Tulare formation of the Coalinga field, but the forms are all specifically distinct. They are likewise separable from similar species in the Orinda lake beds of the Berkeley Hills. It is believed wild ducks distribute the eggs of the species belonging to these genera at the present time, and as such means of distribution probably existed during the Miocene time, it would seem that such forms should prove useful in correlation with other upper Miocene lacustrine beds.

The Petaluma formation in the field northeast of Petaluma is thrown into a series of narrow anticlines and synclines which are not very persistent. Anticlines which are clearly seen in one creek canyon will not be present in the next canyon a half mile east of the first one. These shallow foldings do not extend to Tolay Valley. In the hills west of Eureka School, a well developed syncline was recognized and its corresponding anticline parallels the northwesterly flowing stream which heads at the Eureka School. As was stated above, the Tolay fault limits this formation in a westerly direction. Here the various members of the Petaluma formation are in contact with the Franciscan group and along the fault these lake beds are displaced greatly, steeply dipping beds being the rule. The plane of this fault is almost vertical, in one place measuring 75° to 80°. This fault is an old one as the rocks of the Sonoma group cross it indifferently in its southeastern extension. However, it may have been an important line of movement during late Miocene or early Pliocene.

Merced Group, Pliocene

This group was recognized in Santa Rosa Valley early in the work of the Geological Survey of California, and Gabb, in the volume on the Paleontology of California, described several species of fossils collected from exposures on Mark West Creek. The thickness of these beds is not great nor are they greatly folded in most places in the region of Mark West Creek and Freestone. Osmont represents these beds as having a very decided dip toward the center of Santa Rosa Valley, but observations made at Wilson's Ranch show that the Easterly dip of these beds is but one or two degrees. In and around Freestone low dips were prevalent and apparently the Merced strata are but slightly undulatory, as the Franciscan base is seen in the bottom of Salmon Creek near Freestone and again as a noteworthy mass of serpentine about 3 miles east of Freestone. As the Merced sediments are traced southward on the west side of Santa Rosa and Petaluma valleys, similar conditions were found as respects their general attitude. Locally, however, dips as high as 10° to 15° were recorded around Tomales, Bodega village, and near the Cinnabar School, two miles north of Petaluma, where a westerly dip is recorded. Apparently some minor folding or faulting has occurred in a few places, but the writer questions the synclinal character of Santa Rosa Valley. The hills bordering the Santa Rosa Valley on the east, two to four miles north of Santa Rosa, are composed of tuff and interbedded sandstones with dips at certain localities as high as 40° to the east. The Hayward fault is probably expressed by the sharp separation of the main valley and the eastern bordering hills, and is approximately parallel to the state highway. No other fault characters were recognized in this vicinity, however. Santa Rosa Valley seems to be due chiefly to erosion in soft, nearly horizontal, Merced strata, but complicated by minor folding and faulting. The best known Merced locality is at Wilson's Ranch, a half mile east of Russian River, where a very characteristic, well-preserved fauna occurs. At this place the Merced is composed of hard, gray, conglomeratic sandstone which has an easterly dip of 1° to 2°, and a soft, tuffaceous, yellow sandstone with minor strata of tuff, interbedded. This yellow sandstone with minor tuff members, is the commonest lithologic character of the group throughout this field.

The following fauna was obtained at Wilson's Ranch:

Bathytoma carpenteriana fernandoana Arnold.
Crepidula adunca Sowerby
Drillia mercedensis Martin
Nassa californiana Conrad
Nassa moraniana Sowerby
Natica consors Dall
Olivella biplicata Sowerby

Thais papillus (Linnæus)
Trophon (?), sp.
Arca trilineata Conrad
Cardium, sp.
Glycimeris cf. gabbi Dall
Cryptomya californica Conrad
Macoma cf. edentula Broderip & Sowerby
Paphia staleyi Gabb
Schizothærus pajaroensis Conrad
Solen sicarius Gould
Spisula albaria (Conrad)
Spisula cf. falcata (Gould)
Spisula voyi (Gabb)
Spisula cf. voyi (Gabb)
Spisula (?) sp.

The same general characters mark this group in the region to the west around Freestone. At a locality in the bed of Salmon Creek, one-eighth of a mile from the railroad station at Freestone, in blue gray argillaceous sandstone associated with a yellow tuffaceous sandstone, a Merced fauna was obtained, at a stratigraphic horizon which cannot be over 50 feet above the base of this group, as Franciscan cherts occur only a half mile further up stream and three-quarters of a mile down stream. The Merced beds at this point have an east-west strike and dip of 5° S.

A prominent 4-foot bed of tuff containing casts of marine shells is found 150 feet stratigraphically above this last locality on the road between Freestone and Sebastopol and about one-quarter of a mile east of Freestone. The bed, which is nearly horizontal, is underlain and overlain by yellow tuffaceous sandstone. The material on the crest of the plateau is a light gray sand which is probably of Pleistocene age, though no sharp division line was found which separates these sands from the underlying Merced. The even sky-line as seen here can scarcely be interpreted any other way except that it represents a marine plain of Pleistocene age. (See plates XX and XXVI.)

On Bodega-Valley Ford Road, one-eighth of a mile south of Bodega Postoffice and church, *Crepidula grandis* and *Saxidomus nuttalli* were collected from hard, coarse, gray sandstone with dip of 15° W. and strike of N. 20° E. The sandstone forms the limb of a small syncline which is apparently truncated by a Pleistocene marine plain. Here, as around Freestone, several of the canyon bottoms expose Franciscan rocks. Most of the hills between Bodega and Valley Ford are capped or composed of Merced sandstones. At Valley Ford the rocks of this group are horizontal and the lowermost member consists of a coarse-grained, conglomeratic sandstone or finely-grained conglomerate whose pebbles are nearly all red chert. This resistant sandstone has given rise to the picturesque little buttes seen about the village of Valley Ford. Similar conditions occur around Tomales where the hills are capped by Merced sandstone laid down upon an old erosion surface cut in Franciscan rocks. About two miles west of Tomales, on the Tomales-Dillon's Beach Road, the Merced outcrops boldly as a massive coarse-grained conglomeratic sandstone which has a local dip to the east of 15° with strike of N. 35° W. The sandstone is truncated near this point by a marine plain at an elevation of about 400 feet. (See plates XXI and XXII.) In the sea cliff at Dillon's Beach, Franciscan sandstone with lignite is well exposed so that it is evident the Merced in this vicinity rests upon a Franciscan base at no very great depth. Large casts and one or two good specimens of *Pecten turneri* Arnold, were collected from the roadside about one and one-half miles west of Tomales. The Merced formation was not recognized on the south side of Walker Creek along the coast. Eastward from Tomales toward Petaluma, the road leads through the village of Two Rock where the Franciscan outcrops boldly. In most of the wells dug in the low, flat plain, marine shells were encountered at a small depth. Near the church in this town, on a slight elevation of about 30 feet above the plain around Two Rock, a yellow sandstone entirely surrounded by Franciscan cherts yielded casts of *Leda*, sp., and a few other indeterminate marine shells. Thus we have evidence that the Merced was here laid down upon a decidedly irregular surface. For two or three miles only, Franciscan rocks outcrop along the road. As Petaluma is approached the hills are capped by yellow and tan-colored tuffaceous sandstones. In and around Petaluma good proof of the intimate relations of the marine Merced to the lavas and tuff of the Sonoma volcanic series is seen.

On top of Spring Hill, three miles west and 10 south of Petaluma, the Merced sandstone is found resting upon a basalt flow which is about 50 to 100 feet thick. This basalt flow in turn rests upon the Franciscan, but Merced strata occur at an elevation of 100 feet above sea level, one mile northeast of this hill in what is clearly a sag in the old Franciscan surface. The lower edge of the basalt flow on Spring Hill has an average altitude of about 300 to 400 feet above sea level. In other words, an inequality in the erosion surface of about 300 to 400 feet, is here recognized as a small outcrop of Franciscan occurs at an elevation of about 50 feet in the town of Petaluma, one block west of the corner of Stanley and High streets. At other places in the vicinity, like peculiarities are seen in the distribution of Merced and basalt. One of considerable local interest is found on the corner of Stanley and Howard streets. (See Plate XXVIII.) Loosely consolidated tan sandstones containing what are to all appearances mud balls of volcanic tuff, which are from six inches to a foot in diameter, rest upon an erosional surface of basalt. These beds have a low dip of about one degree to the east. Workers in making the excavations at this place reported marine shells, but the writer was unable to verify this conclusion. These tuffaceous sandstones, however, are areally connected with tan sandstones and gravels of Reservoir Hill, elevation 270 feet, where casts of several pelecypods of Merced age were obtained. The basalt occurring at Stanley Street is relatively thin at this point, as Franciscan schists and cherts occur on Stanley Street one block west of High Street, at a point only 15 or 20 feet lower than the corner of Howard and Stanley streets. One-half mile west of this locality, however, occurs a hill 100 feet high, consisting almost wholly of basalt. This same basaltic area extends southward and rises to an elevation of 200 or 300 feet. From this distributional study it is evident that the basalt was laid down upon an irregular surface cut in the Franciscan. The local unconformity between the Merced and basalt at the corner of Stanley and Howard streets indicates that a part of the flows actually entered the Merced Sea of that time, were partly eroded, and Merced sands were in turn deposited upon them.

This general relation is further demonstrated by the occurrence of Merced fossils beneath the basalts of Burdell Mountain. This hill rises to an elevation of 1560 feet and as the map shows, its main mass consists of basaltic flows and tuff beds of the Sonoma group. On the northwest end of Burdell Mountain basalt, about a mile and a half south of Olompali at an elevation of 300 feet, blocks of conglomerate containing Merced fossils, *Tivela crassatelloides* (Conrad), were found. These blocks, while not in place, were evidently derived from a sandstone member which is exposed in a narrow creek canyon in the vicinity. The Merced at this place rests upon Franciscan rocks. Owing to slides, exposures in most places are meagre, but only 50 to 100 feet occur here, as Dr. M. E. Blanchard, who accompanied the writer to this locality, explored the higher elevation immediately above the sandstones and shales of the Merced, and found nothing but tuffs and lavas. From the evidence we conclude that the lavas and ash deposits of the Sonoma group were laid down close to the shore line of the Merced sea.

The Merced formation occurs in and around Penn Grove and at one locality about one-half mile north of the village, on the state highway, some casts of Merced fossils were collected. The Merced outcrops in the village of Penn Grove consist essentially of tuff and tuff-breccia, thus showing the intimate relationships between the tuffs of the Sonoma group and the marine Merced. Tan-colored sands and gravels entirely surround Meachim Hill, whose top, however, is composed of one of the Franciscan volcanics which is apparently an olivine basalt. A mile and one-half southeast of Penn Grove, Merced strata are in contact with the Petaluma formation of Upper Miocene age. The contact unfortunately is obscure but the inclination of the beds in the Petaluma formation as exposed in Haggin Creek indicates that an angular unconformity probably exists here. The general attitude of the Merced beds is nearly horizontal, while those of the Petaluma formation exhibit dips as high as 12° to the southwest in Haggin Creek.

A series of tan-colored and tuffaceous sandstones is found east and south of Lakeville. No fossils were obtained from the beds, but they are assigned to the Merced upon lithologic grounds. The basaltic conglomerates near Grand View may be of the same age, but they have been somewhat arbitrarily assigned to the Sonoma group because basaltic flows of considerable extent are associated with them.

This general distributional study of the Merced indicates that the Merced was laid down upon a decidedly irregular basement cut in Franciscan rocks, whose relief, judging from the present elevation of Meachim Hill and the Franciscan area at Cherry Station, Santa Rosa Quadrangle, must have been 400 to 500 feet. The surface does not appear to have been wave-cut, but is apparently the result of sub-aerial erosion. In other words, we are dealing with a peneplain which was developed during Ep-Miocene time or Lower Pliocene time, or both. The faunas of the Merced and its lithology indicate that the shore-line of the Merced sea was near the present northeast side of Petaluma Valley.

FAUNA

As was stated above in connection with the general description, the best collecting locality in the Merced group in the region under discussion is at Wilson's Ranch, about one-half mile east of Russian River. The fauna as listed below is typically Merced, and beyond this the writer did not discover any essentially new features. A study of this list readily demonstrates that the locality from near the base of the Merced in this region near Freestone is typically Merced.

DESCRIPTIONS OF LOCALITIES FROM MERCED (PLIOCENE) GROUP

Locality 411. Interbedded fossiliferous s.s. with tuff on ridge 3 miles SE of Freestone. Elevation 600′. Same white sandstone overlying tuff. Dip 10° N Strike E & W. Fossiliferous s.s. in Hall's ranch or Burn's ranch. Schoolhouse in Burnside Dist. Sec. 17, T. 6, R. 9. Coll., J. B. Kerr, July 19, 1916.

Locality 413. One-half mile north of Freestone and 200′ east of trestle in stream. Shaly s.s. and soft s.s. Dip 5° S. Strike E. and W.
Coll., J. B. Kerr, July 22, 1916.

Locality 414. On Bodega—Valley Ford Road one-eighth mile south of Bodega Post-office and Church. Dip 15° W. Strike N. 20° E.
Coll., R. E. Dickerson, July 21, 1916.

Locality 426. One and one-half miles west of Tomales on county road. Merced formation.
Colls., J. B. Kerr and R. E. Dickerson, July 22, 1916.

Locality 545A. One-quarter mile SE. of 546.

Locality 546. Merced fossils from Wilson Ranch, Sonoma Co. Pliocene. Coll., R. E. Dickerson.

Locality 572. Petaluma Quadrangle, 122° 37′ West Longitude, 38° 10′ 5″ North latitude, beneath the basalt of Burdell Mountain.
Coll., R. E. Dickerson, June 21, 1918.

List of species from the Merced (Pliocene) Group

PELECYPODA	411	413	414	426	545A	546	572
Arca trilineata Conrad	..	..	..	..	+	+	..
Cardium cf. meekianum Gabb	..	+	..	..	..	..	..
Cardium, sp	..	..	..	..	..	+	..
Glycimeris cf. gabbi Dall	..	..	..	..	+	..	..
Cryptomya californica Conrad	..	+	..	..	..	..	..
Cryptomya ovalis Conrad	..	..	..	..	..	+	..
Macoma edentula (?) Broderip & Sowerby	..	..	..	..	+	+	..
Macoma nasuta Conrad	..	+	..	..	..	..	..
Mya, sp	..	+	..	..	..	..	..
Panope generosum (Conrad)	..	+	..	..	..	..	..
Paphia staleyi Gabb	..	+	..	..	+	+	..
Pecten turneri Arnold	..	..	..	+	..	..	..
Pecten cf. turneri Arnold	..	+	..	..	..	..	..
Saxidomus (?), sp	+	..	..	..	..	..	..
Schizothærus cf. pajaroensis Conrad	..	+	..	..	..	..	..
Solen sicarius Conrad	..	+	..	..	..	+	..
Spisula albaria (Conrad)	..	+	..	..	..	+	+
Spisula cf. falcata (Gould)	..	..	..	..	+	..	..
Spisula voyi (Gabb)	..	+	..	..	..	+	..
Spisula cf. voyi (Gabb)	..	..	..	..	+	..	..
Spisula (?), sp	..	..	..	..	..	+	..
Tivela crassatelloides (Conrad)	..	..	..	..	..	..	+
GASTROPODA							
Astralium sp	..	+	..	..	..	..	..
Bathytoma carpenteriana fernandoana Arnold	..	..	..	..	..	+	..
Calyptræa inornata Gabb	..	+	..	..	..	..	..
Chrysodomus imperialis Dall	..	+	..	..	..	..	..
Chrysodomus portolænsis Arnold	..	+	..	..	..	..	..
Crepidula adunca Sowerby	..	..	..	..	..	+	..
Crepidula grandis Gabb	+	..	..	..	..	..	..
Crepidula princeps Conrad	..	+	+	..	..	..	..
Drillia mercedensis Martin	..	..	..	..	+	+	..
Nassa californiana Conrad	..	..	..	..	+	+	..
Nassa moraniana Martin	..	..	..	..	+	+	..
Natica consors Dall	..	..	..	..	..	+	..
Natica cf. consors Dall	..	+	..	..	..	..	..
Olivella biplicata Sowerby	..	..	..	..	..	+	..
Thais papillus (Linnæus)	..	..	..	..	+	+	..
Trophon (?), sp	..	..	..	..	..	+	..
CRUSTACEA							
Balanus, sp	..	+	..	..	..	..	..

SONOMA GROUP

Basalts, andesites, rhyolites, tuff breccia, fine-grained tuff, and other agglomerates, comprise the Sonoma group of volcanic rocks which are typically exposed on the western flanks of Sonoma Mountain in the area. Osmont first used the name, Sonoma, in connection with the tuff phase of this great group, and he thought there was only one horizon of tuff beds. His Mark West Andesite and St. Helena Rhyolite were shown to be merely members of this great volcanic mass by Dr. C. E. Weaver,[16] while working upon the Napa Quadrangle.

Dr. Weaver found that andesites or rather basalts, like the "Mark West Andesite" occur at various horizons. He also found that rhyolites and tuffs were variously distributed. Detail studies of the western slope of Sonoma Mountain show the correctness of Dr. Weaver's views.

The Sonoma group covers a large area of country east of the region under discussion, extending over most of the Napa Quadrangle and southward across Carquinez Straits where it is known in the Pinole syncline as the Pinole tuff. The areal mapping in the Petaluma and Santa Rosa quadrangles shows that the lavas of this group probably did not extend much further west than Spring Hill, two miles west of Petaluma, and that these lavas in part were actually interfingered with Merced. The tuffaceous facies of the Sonoma group are represented as interbedded tuff members of the marine Merced, as was described in detail above. In the road cuts a half-mile east of Freestone, a prominent tuff member occurs, and, since numerous casts of marine fossils of Merced age occur here, its origin as a sediment in the waters of the Merced sea is clearly demonstrated.

Osmont[17] made a careful microscopic study of the rocks composing the Sonoma group. His descriptions are in part as follows:

> A specimen of this rock from beneath the Sonoma tuff near the contact on the west limb of the anticline near Mark West Springs showed itself to be microscopically a dark, heavy rock, varying from dark greenish black to brown in color, according to degree of weathering, and

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[16] Weaver, C. E., Unpublished manuscript of Napa Folio, U. S. Geological Survey.

[17] Osmont, Vance, A Geological section of the Coast Ranges north of the Bay of San Francisco, Univ. Calif. Publ., Bull. Dept. Geol., Vol. 4, No. 3, p. 60-61, p. 64, p. 69-70.

sufficiently coarse-grained to enable the lath-shaped feldspars of the ground mass to be readily seen with the naked eye. Scattering phenocrysts of feldspar and of olivine occur up to 4 mm. in length.

Microscopically, this rock is coarse in texture, consisting of a few large phenocrysts of labradorite and olivine scattered through a rather coarsely crystalline ground mass, made up chiefly of labradorite feldspar in well-shaped laths almost universally twined on the albite law, and rounded grains of augite, the structure being the common one called by Rosenbusch "Intersertal". The feldspar phenocrysts, measured by the common method of symmetrical extinctions on the albite twining plane (101), gave a maximum extinction angle of 37.5°. According to Michel Levy, this angle corresponds to a labradorite of about the composition Ab_3An_4. One crystal, rhombic in section, with good cleavages parallel to (001) and (100), and showing no twining lamellae, was evidently cut parallel to the albite twining-plane (010). It gave an extinction angle measured against the trace of (001), of 22°. The extinction fell in the acute angle of the rhomb, making the sign negative. This corresponds to labradorite of a composition between Ab_3An_4 and Ab_3An_5.

Small crystals and grains of magnetite occur, in some cases formed around the ends of the feldspar laths, never included in them. Hematite in flakes and irregular patches, and as a mere stain discoloring the feldspar, is very abundant. It seems to have come from some exterior source as an infiltration. Flow structure is very noticeable, the feldspar laths of the ground mass being drawn out in more or less parallel lines, and wrapped around the ends of the phenocrysts. A little glass is present.

A specimen from beneath the Sonoma tuff on the east limb of the anticline near the contact at Mark West Springs is very similar in appearance to the rock above described from the west contact. It is a dark greenish-black, heavy rock, rather too coarsely crystalline for a basalt, with scattering phenocrysts of feldspar.

Microscopically, also, it is similar. It is somewhat fresher, and contains much less hematite. By Michel Levy's statistical method, the feldspars gave a maximum angle of 43.5°. This indicates a basic labradorite of a composition somewhat more basic than Ab_3An_4, or nearly Ab_1An_2. Augite occurs sparingly as phenocrysts up to .38 mm. in length. These crystals are rounded and corroded as though acted upon by the magma prior to consolidation. The abundant augite in the ground mass occurs in rounded grains lying between the laths of feldspar in the "Intersertal" structure of Rosenbusch. The feldspar laths are short and stout, and invariably twined on the albite law. The augite is of the usual lavender-gray color. It appears to be altering to chlorite of a dark green shade, which stains the rock freely. No olivine was observed in this slide. A slight flow structure was observed. No glass was recognized. A careful determination of the silica contents of this rock gave 65.13%.

This tuff (Sonoma) is a fragmental rock made up wholly of the volcanic material, and characterized by containing numerous fragments of pumice, in size from very small grains up to an inch or more in length. Two silica determinations made on the pumice, from two localities in Santa Rosa Valley, gave respectively 61% and 63% SiO_2. Hence it is andesitic in character.

The rock is usually very light in color and in weight, and, where well exposed, forms a conspicuous feature of the landscape. Certain fine grained varieties of it are easily worked into blocks, which make very good building stone where great strength is not required.

A specimen (St. Helena Rhyolite) from the top of Mount Saint Helena showed the following characteristics:

Microscopically, it is a very light colored, almost white, rock, occasionally slightly reddish from iron stains, notably lacking in ferromagnesian minerals. It has a rough, trachytic-like surface. Numerous large, glassy feldspar phenocrysts can be seen, but no quartz. The ground mass appears to be noncrystalline. Microscopically, this rock is seen to consist of numerous rather poorly formed phenocrysts of potash and soda-lime feldspars enclosed in a fine grained ground mass, composed mostly of glass. No ferromagnesian mineral is present, the only iron-bearing mineral being occasional cubes of magnetite and flakes of hematite, the feldspars frequently being stained with the latter. The most abundant phenocryst is sanidine. Its frequent straight extinction and absence of repeated twining served to distinguish it from the plagioclase present. It is very abundant, and sometimes occurs in well terminated crystals, but usually in broken fragments, frequently badly kaolinized. A relatively small amount of plagioclase occurs, of which the highest extinction angle observed on (010) was 10.5°. This would indicate either albite or oligoclase. The ground mass is very fine grained, and under the high power is seen to be composed of minute fragments of feldspar, apparently sanidine, intimately mixed with unindividualized glass.

Determined solely by its optical properties, this rock would be called a trachyte, since no quartz phenocrysts were observed. A silica determination, however, showed it to contain 72.13% SiO_2. Hence is classed as a *Rhyolite*. A similar rock from above the Sonoma Tuff on the west side of Wooden Valley, Napa County, yielded 72.36% SiO_2.

Detailed studies on the west side of Sonoma Mountain show that the history represented by the different horizons of the Sonoma group is highly complex. Along the Mountain School road in the Santa Rosa Quadrangle, four different beds of tuff separated by basaltic flows were recognized. That erosion intervals occurred between the basalt flows and ash deposits was evidenced by irregular contacts and streaks of basaltic gravels and sandstones between the major tuff strata and the basaltic flows. The Neohipparion gidleyi beds at Lawlor's Ranch indicate that some of these intervals were of considerable duration. These beds are fairly well exposed on Lawlor's Ranch just below the ranch house, between the 600 and 700 foot contours, one mile S. 30° E. from the Mountain School, about 6 miles N. E. of Petaluma at an old coal prospect. About 60 feet of sandstone, lignite, and carbonaceous shale, and freshwater chert is found in a small canyon. Considerable sliding has taken place and it is difficult to tell where the freshwater chert fits in the section. Beneath a lava flow, a stratum of sandstone occurs, then apparently a three- or four-foot seam of coal resting upon carbonaceous shale, and possibly the freshwater chert next; and finally a coarse sandstone is found resting upon compact tuff. The thickness of these members was not observable. The coal as reported by Mrs. Thompson, a daughter of Mr. Lawlor, was of good quality when mined and she also stated when interviewed in Petaluma, that the horse remains, *Neohipparion gidleyi* Merriam,[18] were taken out of the beds associated with the coal. The coal and freshwater chert indicate that a considerable time would be required for their formation.

These beds outcrop in a few other places southeast of Lawlor's Ranch and, since they are less resistant than the underlying tuff of the Sonoma group, are worn away easier than the tuff, leaving a plateau underlain by tuff with the Neohipparion beds in the scarp-like hillside. A generalized N-S section running north from Adobe fort to the Petaluma Reservoir, shows the following sequence:

Basalt
Tuff
Basalt
Conglomerate
Basalt
Neohipparion beds
Tuff
Unconformity, base of Sonoma Group
Petaluma formation

From the end of this road to the top of Sonoma Mountain, basalt predominates. These lavas on the Hayward Rift have not been much disturbed and the vertical displacements may be measured probably only in tens of feet. The top of Sonoma Mountain is to all appearances a plateau due to a nearly horizontal sheet of the basaltic lava. The distribution of the lavas and tuffs is not uniform, since at some places lavas rest directly upon the Petaluma formation while at other localities tuff intervenes. Such is the case at the locality where bituminous sands occur in upper Lynch Creek, about half a mile northwest of Mountain School, Santa Rosa Quadrangle. At this place a fault whose exact position was not determined has disturbed the Neohipparion gidleyi beds and given them a pronounced dip of 25° W. These bituminous sands and carbonaceous shales rest upon basalt and

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[18] Merriam, J. C., New species of the Hipparion Group from the Pacific Coast and Great Basin Provinces of North America; Univ. Calif. Publ., Bull. Dep't. Geol., Vol. 9, No. 1, pp. 1-8, 1915.

in turn are overlain by basalt. Plate XXXVIII shows the approximate sequence in Lynch Creek. The cavities in the overlying basalt are in some places filled with a thick petroleum residue and some of the dark brown, medium-grained sandstones are impregnated with petroleum. These sands yield a very good petroleum test when shaken out with chloroform. The Petaluma formation is not a probable source of the oil but it apparently has come up from below, along a fault. The Monterey shale is probably its original source and this group apparently underlies the Petaluma formation in the region. Another indication of petroleum, a seep, is reported about one mile southwest of Ducker's ranch house. Two wells of 100 feet and 400 feet in depth were drilled on the Ducker ranch. A heavy gas pressure was reported.

SONOMA PETRIFIED FOREST

It is always a difficult question to decide the relative importance of unconformities and the time intervals between successive outbursts of lava, volcanic ash, or tuff-breccia. A very rough measure of time is found at the Sonoma Petrified Forest, which is located about eleven miles northwest of Santa Rosa and five miles west of Calistoga, a town at the head of Napa Valley. Most of the trees in this "forest" were covered, or nearly covered, by tuff and tuff-breccia, belonging to the Sonoma group of volcanics, when discovered by Mr. Chas. Evans in 1871. Mr. Evans excavated the trees and exposed several large redwoods and firs to view. This excellent work has been continued by the present owners, Mr. and Mrs. D. G. Bockee, and there are now about eight fine trees which have been laid bare for inspection. (See Figures 1 and 2, Plate XXXI.) The "Queen of the Forest" is a large redwood about twelve feet in diameter at its base. About eighty feet of this tree is preserved in stone. As the picture indicates, it is broken somewhat, but its fragments were so arranged when it was excavated that the position of the tree as it was toppled over and buried by a great flow of volcanic mud and ash, has been maintained to this day. A smaller but more nearly perfect specimen is shown in Figure 2, Plate XXXI. This tree was almost completely buried in tuff-breccia when discovered. Its natural taper is readily apparent and like the "Queen of the Forest" its top is toward the southwest and base toward the northeast. The "Monarch" is a large fir whose exposed, preserved length is ninety feet and whose diameter at the base is about ten feet. It also has the orientation of the trees described above. In all of these trees the gradual replacement of the woody material by silica carried by waters which percolated through the covering of tuff-breccia has been so complete that the fibers and peculiar texture of the various species have been retained. The direction of all of the trees in the "forest" was measured and in all cases was found to lie between N. 30° E. and N. 45° E., with tops toward the southwest. It is evident from these facts that the volcanic mud and pumice came in a great volume from the northeast. A study of the vicinity shows that a lava lies beneath the tuff-breccia and light gray pumice. A section in a small creek, a hundred yards south of the petrified trees proves that the forest grew upon a soil formed from this lava. The lava was probably a basalt, but the rock is so badly weathered that it is impossible to classify it with certainty. How long it takes to form from such a lava a soil sufficient to maintain a great forest is an unknown factor, but it must be estimated at least in terms of hundreds of years. The "Queen of the Forest" was probably at least a thousand years old when the great catastrophe occurred which wiped out this Pliocene forest. From such data, we may assume that the time interval between the lava flow and the deposition of tuff and tuff-breccia must be estimated in terms of a few thousand years as a minimum. The time interval represented by the Neohipparion gidleyi beds of Sonoma Mountain is probably of about the same order as the above described case. We must be generous in the use of time when we are concerned with geologic estimates and such an interval as indicated above is probably not sufficiently long to justify minute sub-division of the geologic scale. In broad correlations it is not possible to consider many of these cases.

CORRELATION

As was shown above, the marine Merced is distinctly interfingered with the basalts and tuffs of the Sonoma group. Around Freestone, tuffs containing Merced fossils were found interbedded with sandstones and sandy shales of Merced age. At Spring Hill, west of Petaluma, Merced strata rest upon a basalt flow, but at the northwest end of the Burdell Mountain mass (Petaluma Quadrangle), conglomerate containing Merced fossils occurs, resting upon Franciscan with several hundred feet of basalt and tuff-breccia above the Merced strata. In the vicinity of Penn Grove the intimate relations between Merced sandstones containing marine fossils and tuff-breccia is quite clear. In this vicinity the nearly horizontally bedded Merced rests unconformably upon the Petaluma lake beds of Upper Miocene age, and a like relation exists between the basalts and tuffs and the Petaluma formation on the west side of Sonoma Mountain. The stratigraphic relations are entirely clear and in this way the Merced group is thus shown to be the correlative of the Sonoma group. As was shown above, the Neohipparion gidleyi beds belong with the Sonoma group and are not associated with the Petaluma.

Neohipparion and Hipparion, which are typical horses of the Pliocene, occur also in beds of the Orinda formation of the Berkeley Hills and in the Etchegoin and Jacalitos of the western border of the San Joaquin Valley. Merriam[19] describes the Orinda and Siesta formations and their faunas as follows:

The Orindan and Siestan formations occurring in the hills immediately to the east of Berkeley form the larger part of a thick accumulation of freshwater and alluvial beds resting unconformably upon the marine Miocene. The Orindan formation is the lower portion of these beds, and comprises a great thickness of clays, shales, sands, conglomerates, and tuffs, with occasional beds of limestone. The Orindan is followed by a series of igneous rocks consisting mainly of andesite and basalt. The Siestan rests upon the lavas covering the Orindan, and is in turn covered by a volcanic series made up largely of basalt.

The section, from the base of the Orindan to the top of the lavas above the Siestan, contains no marine fossils. It shows scattered through it a few remains of freshwater Mollusca and Crustacea, land Mollusca, land plants, and land or freshwater vertebrates. The accumulation as a whole is evidently the result of deposition in a basin which was at some time occupied, at least in part, by freshwater, and at other times may have received purely alluvial deposits.

Remains of early horses have been found at two localities in the Orindan beds. No specimens representing this group are certainly known from the Siestan. It is stated that bones of a horse were found in a shaft sunk in Siestan beds on Frowning Ridge near the upper end of Telegraph Canyon.

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[19] Merriam, J. C., Vertebrate Fauna of the Orindan and Siestan beds in Middle California, Univ. Calif. Publ., Bull. Dept. Geol., Vol. 7, pp. 373-374; pp. 376-377, and pp. 384-385.

New Species of the Hipparion Group from the Pacific Coast and Great Basin, Univ. Calif. Publ., Bull. Dept. Geol., Vol. 9, p. 3, 1915.

Tertiary Vertebrate Faunas of the North Coalinga Region, Trans. Am. Philos. Soc., Vol. 22, part 3, Philadelphia, 1915.

A single tooth was obtained by Mr. J. P. Buwalda from Mr. Williams, who discovered it in extensive Orindan exposures about two and one-half miles from the mouth of Tassajara Canyon, on the southwest side of Mount Diablo. The specimen from Tassajara Canyon and the better preserved tooth from Bolinger Canyon seem to represent different species. The second specimen from near Bolinger Canyon is imperfectly preserved, but is possibly different from the other two teeth.

Nomland[20] describes the occurrence of vertebrates in the (Jacalitos) lower Etchegoin as follows:

As has already been mentioned, a large quantity of fossil leaves and petrified wood is found in the highly colored, perhaps land-laid beds mapped as basal Jacalitos. This collection may, when carefully studied, assist in determining the age of this formation. In these beds fossil remains of the three-toed horse, *Neohipparion molle* Merriam, were found.

The finding of *Pliohippus*? in the gravels two hundred feet above the basal Jacalitos, or in the bed mapped by Arnold and Anderson as their lowest Jacalitos member, has already been mentioned in this paper.

Above this no invertebrate or vertebrate fossils have thus far been found until reaching the Glycymeris coalingensis zone, or lowest Etchegoin. The Pliohippus stage of the development of the horse is represented here in the basal beds and a few hundred feet upwards. This zone has therefore been called the Pliohippus coalingensis zone by Professor Merriam.

Merriam in the "Tertiary Vertebrate Faunas of the North Coalinga Region," describes the relations of Neohipparion as follows:

The species represented by specimen 21370 is evidently distinct from the Ricardo forms, and from all other described Hipparion species of the Pacific Coast and Basin provinces. Whether it is a more or a less advanced species than the Mohave form is not entirely clear. The slightly greater length of crown, and the large, much-flattened protocone may indicate a more advanced stage in the Coalinga species. The Neohipparion species represented by no. 21370 is described as *Neohipparion molle*. This species is characterized by length and narrowness of upper molar crown, simplicity of enamel borders of the narrow fossettes, and unusually large anteroposterior diameter of the laterally compressed protocone. . .

The Jacalitos fauna as now known is characterized by the presence of Neohipparion occurring only in the lowest beds, and by Pliohippus or Protohippus apparently occurring a little higher than the Neohipparion specimens in the basal portion of the section.

Although *Neohipparion gidleyi* from the Sonoma group, *Neohipparion molle* from the basal beds of the (Jacalitos) Etchegoin formation north of Coalinga, and *Hipparion platystyle* from Orinda beds two and a half miles southwest of Tassajara Post Office, are specifically different, yet all three

[20] Nomland, J. O., Relation of the Invertebrate to the Vertebrate Faunal Zones of the Jacalitos and Etchegoin Formations in the North Coalinga Region, California. Univ. Calif. Publ., Bull. Dept. Geol., Vol. 9, No. 6, 1916.

belong to the Hipparion group and probably represent closely related forms. Recently, Dr. Chester Stock secured a vertebrate fauna from sandstone beds just above the upper tuff member of the Pinole formation and conformable with this tuff, and the assemblage of mammalian types is apparently an Orinda fauna. The Pinole Tuff-Orinda strata in the Pinole syncline are very closely connected areally with tuff beds of the Sonoma group north of Carquinez Straits. Since the volume of tuff diminishes gradually as one travels from Napa toward the south it is suggested strongly that the volcanic ash and pumice came from a northerly direction. The thickness of the Pinole tuff is much less than the tuff beds around Napa. While this is not conclusive evidence, as Carquinez Strait intervenes, it fits in with evidence derived from the study of the vertebrate faunas.

In brief then, the Merced has been shown to be the equivalent of the Sonoma group through stratigraphic and areal relations. The Sonoma group in turn is areally connected with the Pinole tuff and the Orinda formation of the Berkeley Hills and by means of *Neohipparion gidleyi*, its close faunal relationship is shown. The fauna of the (Jacalitos) Lower Etchegoin is related to that obtained from the Neohipparion gidleyi beds of the Sonoma group.

Millerton and Tomales Formations

One of the interesting results of the work in the region of Tomales Bay was the discovery of a Pleistocene fauna in the Millerton formation which indicated a climatic condition similar to that of San Diego today. Two or three excellent collecting localities were found in the headlands on the northeast side of Tomales Bay. A small but distinctive Pleistocene fauna of the same type was found in terrace deposits overlying the Millerton formation of Lower or Middle Pleistocene age. The beds containing this fauna will be referred to as the Tomales formation, owing to their occurrence also on the northeastern side of Tomales Bay.

The type locality of the Millerton formation is in the headland near Millerton Station, northeast of Inverness on Tomales Bay. On the west side of this headland, the beds here exposed have a strike of north and south and a dip of

10° to the east. The lowermost member as exposed in this cliff-section is an oyster bed made up almost wholly of the remains of *Ostrea lurida*. Resting upon these oyster beds is a bed of flesh-colored clay containing numerous specimens of *Corbula fragilis* Hinds. These Corbula beds (Cal. Acad. Sci. Loc. 563) are in turn overlain by sandstone and a prominent conglomerate member whose pebbles are composed of schist, chert, sandstone and granite. Two hundred yards northeast of the headland, lignitic sands containing wood and pine cones, oyster shells and *Chione undatella,* rest upon a conglomerate which dips 1° to 2° to the west. These horizontal lignitic beds exhibit a striking relation to the underlying conglomerate in that roots of pine trees have penetrated the contact between the two formations, thus indicating in quite conclusive manner, a notable Pleistocene unconformity. These lignitic beds and the overlying tan-colored sandstone conglomerates are assigned to the Tomales formation. The pine cones are not badly damaged and do not show wear by running water or by waves. They have been identified by Miss Alice Eastwood, Curator of Botany, California Academy of Sciences, as *Pinus radiata*. These cones, as well as *Chione undatella,* indicate a climatic condition during the upper Pleistocene considerably warmer than that of today. *Chione undatella* does not range further north at the present time than San Pedro, California, and *Pinus radiata* has its present northern limit in San Mateo County.

California Academy of Sciences Localities 561 and 563 are on Millerton headland, so that both characteristic Pleistocene faunas are present in the one vicinity. The base of the Millerton formation is not exposed at the type locality, the block making Millerton headland being lodged between two fault lines of the San Andreas Rift. On the north side of Tom's Point near the entrance to Tomales Bay, basal beds of the Millerton formation rest unconformably upon Franciscan chert and glaucophane schist. The basal member is a conglomerate composed of fragments of chert, schist, tuff and tuff-breccia, and its matrix is a dark gray andesitic mud. Pieces of bark, a sixteen-inch tree trunk and cones of *Pinus radiata* are imbedded in it. California Academy of Sciences Locality 412 is in sandy shales overlying the basal conglomerate. These shales contain essentially the same fauna as that of the type locality of the Millerton formation. Tom's Point, as will be seen from a study of Figure 1, Plate XXXII, and Figures 1 and 2, Plate XXXIV, has been much disturbed by faulting along the San Andreas Rift. Typical fault-sag ponds occur on the top of Tom's Point along two marked lines of faulting. The fault-sag pond shown in Figure 1, Plate XXXII, is on the western end of the point. Another fault-sag pond occurs about a hundred yards east of this locality, marking a fault which is apparent in the picture of the cliff-section shown in Figure 1, Plate XXXIV. The two pictures shown in Plate XXXIV indicate considerable disturbance of the Millerton formation, as dips as high as 20° to 25° are common at this point. The best stratigraphic section of the Millerton formation was found in the headland a mile and a half northwest of Millerton Station, on the northwest side of this point. Enough fossils were obtained from these beds to prove that the fauna was the same as that of the Millerton at its type locality. In the west end of the cliff-section, 50 feet of conglomerate is exposed and it exhibits a pronounced dip of 23° E. with strike of N. 20° W. This strike and dip is quite uniform for several hundred feet until a point is reached about sixty feet west of the railroad, where one of the faults of the San Andreas Rift Zone has shattered the section. The conglomerate strata at the west end of the point are 65 feet in thickness and are overlain by 85 feet of carbonaceous tan-colored sandstone and dark gray shale containing marine shells in its middle portion. A prominent conglomerate member two feet in thickness is next observed. The latter deposit is overlain by more carbonaceous tan-colored sandstone and dark gray shale, 23 feet in thickness. A fault apparently intervenes at this point and the underlying strata are not exposed east of it. Near the railroad an erosional unconformity appears to be present between the Millerton formation of Lower or Middle Pleistocene age and the Tomales formation of Upper Pleistocene age. The Tomales formation at this point is composed of a tan-colored sandstone and conglomerates—perhaps fanglomerates would be a better designation—lighter in color than the tan-colored sandstones of the Millerton formation. The outcrops of the Tomales formation in this vicinity were carefully searched for fossils but no shells were found which were unmistakably in place. The Tomales formation is apparently largely composed of land-laid deposits and it appears probable that much of the loosely consolidated sandstone represents material composing Pleistocene alluvial fans. Most of the headlands on the northeast side of Tomales Bay are thinly coated with these loosely consolidated sandstones and conglomerates of the Tomales formation. The even-topped terraces one-quarter of a mile northwest of Point Reyes Station are composed of tan-colored sands and gravels whose pebbles are schist, chert, sandstone, basalt and granite. The occurrence of granite pebbles in these gravels is noteworthy, as it shows that a part of the gravels is due to contributions from the southwestern side of Tomales Bay, thus apparently indicating that the bay was not so extensive during the Tomales-Pleistocene time as today or during the period of deposition of the Millerton formation.

FAUNA OF THE MILLERTON FORMATION

A list of species obtained from the Millerton formation is shown in the accompanying table.

DESCRIPTIONS OF CALIFORNIA ACADEMY OF SCIENCES PLEISTOCENE LOCALITIES OF THE MILLERTON FORMATION

Locality 412. Cliffs along northeast shore of Tomales Bay, about one-half mile from Ocean. Fossiliferous conglomerate reef in Pleistocene. This reef is a hard conglomerate made up of schist pebbles on shore line in Pleistocene. Above it is clay shale and soft yellow sandstone.

Coll., J. B. Kerr, July 24, 1916.

Locality 561. Pleistocene fossils occur on east side of Tomales Bay, east of Inverness Yacht Club.

Coll., R. E. Dickerson, April 4, 1918.

Locality 563. Pleistocene fossils on point on east side Tomales Bay, east of Inverness Yacht Club.

Coll., R. E. Dickerson, April 4, 1918.

List of Species from Millerton Formation, Lower or Middle Pleistocene of Tomales Bay

PELECYPODA	412	561	563	PRESENT GEOGRAPHIC RANGE OF SPECIES	GEOLOGIC RANGE OF SPECIES
Cardium substriatum Conrad	×	..	..	Catalina Island to Acapulco (Dall)	Pleistocene to Recent (Arnold)
Cardium quadrigenarium Conrad	×	×	×	Santa Barbara, Calif., to Todos Santos Bay, Lower Calif. (Dall)	Miocene to Recent (J. P. Smith)
Cardium corbis Martyn	×	..	..	Bering Sea to San Diego (Dall)	San Pedro Pleistocene to Recent (Arnold)
Chama cf. pellucida Broderip	×	..	..	Oregon to Chile and Galapagos Islands (Dall)	Etchegoin Pliocene to Recent
Cryptomya californica Conrad	×	..	×	Chichagof Island, Alaska, to Topolobampo, Mexico (Dall)	Pliocene to Recent
Corbula fragilis Hinds	×	×	×	Monterey, Calif., to Salina Cruz, West Coast of Mexico (Dall)	Pleistocene to Recent
Chione undatella Sowerby	×	×	×	San Pedro, Calif., south to Guayaquil (Dall)	Pleistocene to Recent
Glycimeris septentrionalis Middendorff	..	..	×	Aleutian Islands to Puget Sound (Dall)	Miocene to Recent
Hinnites giganteus Gray	×	..	..	Aleutian Islands to Magdalena Bay, Lower California (Cooper)	Miocene to Recent
Leda taphria Dall	×	..	×	Bodega Bay, Calif., to Lower California (Dall)	Miocene to Recent
Metis alta Conrad	..	..	×	Santa Barbara, Calif., to San Diego, Calif (Dall)	Miocene to Recent
Macoma nasuta Conrad	×	..	×	Kodiak Island and Cook Inlet south to Scammon Lagoon, Lower California (Dall)	Miocene to Recent
Monia macroschisma Deshayes	×	..	..	Japan; Unalaska to San Diego, Calif (Cooper)	San Pablo Miocene to Recent (J. P. Smith)
Ostrea lurida Carpenter	×	×	×	Sitka to Cape St. Lucas (Dall)	Etchegoin Pliocene to Recent (J. P. Smith)
Paphia tenerrima Carpenter	×	..	..	Puget Sound to San Quentin Bay, Lower California (Dall)	San Pablo Miocene to Recent (J. P. Smith)
Paphia staminea Conrad	..	..	×	Commander and Aleutian Islands to Kamchatka and North Japan and to Puget Sound and Socorro Islands (Dall)	San Pablo Miocene to Recent (J. P. Smith)
Phacoides nuttalli Conrad	×	..	..	Monterey to San Diego (Cooper)	San Diego Pliocene to Recent (Arnold)

List of Species continued on the following page.

List of Species from Millerton Formation, Lower or Middle Pleistocene of Tomales Bay—Continued.

PELECYPODA	412	561	563	PRESENT GEOGRAPHIC RANGE OF SPECIES	GEOLOGIC RANGE OF SPECIES
Pecten latiauritus Conrad	×	×	×	Monterey, Calif. to Lower California (Dall)	Pleistocene to Recent (Arnold)
Semele decisa Conrad	×	..	×	San Pedro to San Diego, California (Dall)	Pleistocene to Recent (Arnold)
Schizothærus nuttalli (Conrad)	×	..	..	Wrangell, Alaska, to San Diego (Dall)	Pliocene to Recent (Arnold)
Tagelus californianus (Conrad)	..	..	×	Santa Barbara, Calif., to Gulf of Tehuantepec (Dall)	Pliocene to Recent (Dall)
GASTROPODA					
Astyris gausapata (Gould)	..	..	×	Alaska to San Diego (Hanna)	Pleistocene to Recent (J. P. Smith)
Calliostoma tricolor Gabb	×	..	..	New Year Point to San Diego (Cooper)	San Pedro Pliocene to Recent (Arnold)
Nassa perpinquis Hinds	..	..	×	San Francisco to Lower California	Pliocene to Recent
Nassa californiana Conrad	×	..	..	Drake's Bay to Cerros Island, Lower California (Arnold)	San Pablo Miocene to Recent (J. P. Smith)
Olivella biplicata Sowerby	×	..	..	Straits of Fuca to San Diego (Cooper)	Etchegoin Pliocene to Recent (J. P. Smith)
Tornatina cerealis (Gould)	..	..	×	Monterey to San Diego	Pleistocene to Recent (Arnold)
Thalotia caffea (Gabb)	..	..	×	Monterey to San Pedro (Cooper-Raymond)	Pliocene to Recent (Arnold)
Astyris tuberosa (Carpenter)	..	..	×	Neah Bay to San Diego (Cooper)	Pliocene to Recent (J. P. Smith)
Crepidula onyx Sowerby	×	..	×	Panama, Central America (Carpenter)	Upper Miocene to Recent (J. P. Smith)
Fissuridea murina (Carpenter)	..	..	×	San Pedro to Catalina (Williamson)	Pleistocene to Recent.
Lunatia lewisii (Gould)	×	..	×	Straits of Fuca to San Diego (Cooper) Japan (Tryon)	Monterey Miocene to Recent (J. P. Smith)
Monoceras engonatum Conrad	×	..	..	Bolinas to San Diego (Cooper)	San Pablo Miocene to Recent (J. P. Smith)
Murex festivus Hinds	×	×	×	San Pedro to Lower Calif. (Cooper)	Pleistocene to Recent (Arnold)
Nassa mendica Gould	..	..	×	Sitka to San Diego (Cooper)	Pliocene to Recent
SCAPHOPODA					
Dentalium neohexagonum S. & P.	×	×	..	Monterey to Mexico (Hanna)	Pliocene to Recent (Arnold)
CRUSTACEA					
Balanus concavus Bronn	×	..	..	Panama to San Pedro, Calif., Philippine Archipelago, Australia (Darwin)	Miocene to Recent

Interpretation of Fauna of the Millerton Formation

Professor J. Perrin Smith, who examined the fauna collected from the beds of the Millerton formation and Tom's Point, recognized that the types in this assemblage were of species considered characteristic of a warm period of the Pleistocene, and he stated that the fauna was equivalent to that obtained from the upper San Pedro beds by Dr. Ralph Arnold. The careful work of Mr. Thomas Oldroyd has indicated, according to Professor Smith, that such forms as *Chione undatella* were restricted to the Upper San Pedro deposits and did not range downward into the beds of the Lower San Pedro Pleistocene. The writer has prepared a list of the forms obtained from the Millerton beds and has given the present known ranges of these forms in the Recent fauna. None of these species is extinct, but many of the forms, such as *Cardium substriatum* Conrad, *Cardium quadrigenarium* Conrad, *Corbula fragilis* Hinds, *Chione undatella* Sowerby, *Metis alta* Conrad, *Semele decisa* Conrad, *Tagelus californianus* (Conrad), *Pecten latiauritus* Con., *Dentalium neohexagonum* S. & P., *Crepidula onyx* Sowerby, and *Murex festivus* Hinds, are now restricted in range to regions south of Santa Barbara or Monterey. Ranges are given according to available literature. The other forms in this fauna are species which at present have a great range along the Pacific Coast. From the study of this fauna the writer is led to complete agreement with Professor Smith's correlation. With one exception, this is the first time that a fauna of a warm period of the Pleistocene has been reported from San Francisco Bay vicinity. Faunas collected from the Pleistocene terraces around Santa Cruz contain species which are characteristic of that region today. Pleistocene faunas collected by Mr. Bruce Martin from marine terraces on the Oregon Coast also yield Recent species which occur commonly in waters of the ocean at that locality. The Pleistocene fauna of Merced Beach, San Francisco Peninsula, likewise does not suggest any conditions different from those of today.

Dr. Ralph Arnold[21] in his notable memoir on the marine Pleistocene and Pliocene of San Pedro, California, correlated

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[21] Arnold, Ralph, Memoirs of the Calif. Acad. of Sciences, Vol. 3, The Paleontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, California, p. 49, 29-30, 1903.

certain Pleistocene beds which are exposed along the Straits of Carquinez at Rodeo with his warm water facies of the Pleistocene, the Upper San Pedro. Concerning this Arnold states:

The Pleistocene deposits on the shore of San Pablo Bay between the Union Oil Refinery and Point Pinole have been visited by Dr. Merriam and the writer. The deposits, which rest on the upturned edges of the San Pablo strata, consist of horizontally bedded layers of sand, gravel, and clay. Teeth of the mammoth, and bones of the giant sloth and extinct bison have been found in these Pleistocene layers by Dr. Merriam. In certain places the Pleistocene layers consist almost entirely of oyster and mussel shells. Fossils from the Pleistocene deposits on San Pablo Bay between the Union Oil Refinery and Point Pinole are, *Ostrea lurida*, *Ostrea conchaphila*, *Mytilus edulis*, and *Tagelus californianus*. The character of these Pleistocene strata and of the fauna leads the writer to correlate them with the upper San Pedro series.

Arnold further states concerning his upper San Pedro as follows:

The upper San Pedro beds do not represent the top of the Pleistocene. The fauna of these upper beds, although having many species in common with the living fauna of the same locality, is still quite distinct. This would suggest a period of considerable length since the deposition of the strata. The number of distinctly southern forms living at San Pedro during the period of deposition of the upper beds also shows that there has probably been a change in climatic conditions since that time. A raised beach unconformable with the upper San Pedro strata at Deadman Island shows that there have been orographic movements since the upper San Pedro beds were deposited. All of this evidence, then, leads to the conclusion that there has been a sufficient lapse of time since the deposition of the upper San Pedro strata, to admit of marked faunal and orographic changes.

Lawson[22] in his "Geomorphogeny of the Coast of Northern California," states in the concluding paragraph concerning the Rodeo beds that, "Seemingly the last event is a slight uplift in the vicinity of the Straits of Carquinez."

Arnold's tentative correlation was probably based upon the occurrence of *Tagelus californianus* (Conrad) whose present range is from Santa Barbara to the Gulf of Tehuantepec, and indicates that it is restricted to warmer waters than those of the San Francisco Bay of today. As noted above, Arnold clearly recognizes that the Upper San Pedro fauna is not

[22] Lawson, A. C., Univ. of Calif. Publ., Bull. Dept. Geol., Vol. 1, p. 271, 1894.

the latest Pleistocene, but he did not consider the possibility that more than one warm epoch might be represented in the marine sequence of the Pacific Coast. A small fauna from California Academy of Sciences Location 571, situated 200 feet northeast of California Academy of Sciences Location 562, on the northeast end of the headland opposite Inverness Yacht Club, on the east side of Tomales Bay, three-quarters of a mile northeast of Millerton Station, demonstrates that a second warm epoch was probably present in the Tomales Bay region. This fauna consisting of *Chione undatella* Carpenter and *Ostrea lurida* Carpenter, is closely associated with cones of *Pinus radiata*. The two localities just mentioned are separated by an unconformity between the Tomales and Millerton formations.

Later work by Professor J. C. Merriam[23] and others upon the vertebrate and invertebrate faunas obtained from the Rodeo beds gives evidence that the vertebrates from this locality do not apparently represent the same stage of evolution as those from the Rancho la Brea beds. To quote from this guidebook:

On the borders of a swamp near the oil refinery of the Union Oil Company are exposed vertical strata of Pinole tuff, composed of light yellowish or white pumice. These strata dip at a relatively low angle on the southwest side of the syncline. The axis of the asymmetric Pinole syncline passes through the swamp. The Pinole tuff, having a thickness of about 1000 feet, was laid down in part, at least, in a lake basin. Freshwater shells belonging to the genus Physa have been found in the strata on the eastern side of the swamp. Rodeo-Pleistocene beds rest upon the Pinole tuff at this point. Further west the Pinole tuff is exposed in the railroad cuts near Rodeo Station. Just west of this station easterly dipping beds of the upper San Pablo are exposed. At Hercules Station the shattered Monterey strata which form the lower portion of the western limb of the Pinole syncline are seen. West of Pinole Station the Pinole tuff is in contact with the Monterey.

The Pleistocene deposits of San Pablo Bay have been referred to frequently as the Rodeo beds. They are well exposed in the sea cliffs near Rodeo and Pinole. Near Rodeo Station the horizontal Pleistocene strata rest upon sharply tilted beds of San Pablo-Miocene and Pinole Tuff-Pliocene. At a number of localities the basal layers of the Rodeo are made up almost entirely of marine shells, comprising mainly oysters and mussels. Above the shell layer the deposits grade into beds of estuarine or alluvial origin. The thickness of the Pleistocene in this region is commonly not over 40 feet.

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[23] Merriam, J. C., and others, Preliminary Program and Outline for Excursions for Meeting of the Paleontological Society, pp. 8-10, 1915.

Not more than seven marine types are known from the Rodeo. The complete list of species is as follows:

Ostrea lurida Conrad	Tagelus californianus (Conrad)
Mytilus edulis Linnæus	Epitonium hindsii (Carpenter)
Cryptomya californica (Conrad)	Balanus, sp.
Cardium corbis (Martyn)	

All the marine species of the Rodeo-Pleistocene are still living on the Pacific Coast, and with the exception of *Tagelus californianus* all are found in the vicinity of San Francisco Bay. This species is now limited to the relatively warm waters south of Santa Barbara. All of the Rodeo species are now typical marine forms, but may also appear in estuaries. These Pleistocene beds were presumably deposited during a period of relatively warm climate, and may therefore be approximatly contemporaneous with the upper San Pedro Pleistocene of Arnold.

Fossil bones of mammals and birds have been found at several horizons in the Rodeo formation. Remains of Elephas are known from the shell layers at the base of the section. The vertebrate fauna includes the following forms:

Equus, sp. (possibly new)	Felis, near atrox Leidy
Bison, near antiquus Leidy	Smilodon?, sp.
Elephas columbi Falconer	Æcmophorus occidentalis (Lawrence)
Camelid (possibly new)	
Mylodon, sp.	

The mammal fauna of Rodeo is not closely comparable with that of any well-known stage on this coast. The camel and the horse do not correspond to the species of Rancho La Brea, but later collections may show that the fauna is not widely different in stage from that of Rancho La Brea.

As is pointed out above, the contrast in the lithology of the Millerton and Tomales formations is striking and the unconformity between the two deposits is likewise well marked. As was stated in the introduction, the evaluation of an unconformity in a Rift Zone area is a difficult one, as events happen here with startling suddenness. Although the writer has considered this carefully, several facts cause him to believe that this unconformity may represent a long period of Pleistocene time, and that the Millerton formation was deposited during one warm epoch — possibly an interglacial stage—and the Tomales formation during a later warm epoch. When the fauna of the Millerton is studied, the absence of such genera as Haliotis Echinarachnius, and other forms characteristic of an open coast, is a noteworthy feature. The forms composing the fauna are, on the other hand, such as can live in land-locked bays. The character of the lithology and the sudden changes in the lithology of the Millerton formation, such as the mixture of conglomerates and clays are strikingly similar to the deposition going on in Tomales Bay at the present time.

Dr. J. C. Merriam[24] in a paper entitled "Ground Sloths in the California Quaternary" has described the humerus of a large ground sloth from the northeast shore of Tomales Bay, and gives the following note upon the occurrence of this interesting form:

> The place pointed out to Mr. Calkins as that from which the humerus was obtained is in a small run about three-quarters of a mile southeast of Hamlet and about 100 feet above the level of the bay. The stream in the run has cut down quite sharply for about 12 feet into a loose, sandy clay at the spot where the specimen was obtained. Above this point it flows through or over deposits similar to those just mentioned, and over rocks of the Franciscan series, so that the specimen must be derived from one or the other of these formations. As the Franciscan rocks are of middle Mesozoic age and have suffered much disturbance, the only possible source of such a specimen as that which we have under consideration is the more recent deposit.
>
> Incoherent, yellowish, sandy clays, similar to those just mentioned form the most prominent feature of the geology along the east side of Tomales Bay between Point Reyes Station and Hamlet. In many places they form prominent seacliffs up to 40 feet in height. They are everywhere unsolidified and frequently show horizontal stratification. Mr. Calkins considers the beds in the stream cutting in which the humerus was found as an extension of this deposit up the slope of the hill. Judging from their incoherent nature and horizontal stratification, these beds are certainly much younger than the latest Pliocene in the region. Excepting the humerus, the only fossil obtained from them is a badly worn Elephas tooth, which was picked up on the shores of Tomales Bay near Point Reyes. This formation resembles the deposits along the shores of San Pablo and Suisun bays, in which a Quaternary fauna, both molluscan and mammalian, has been obtained by the writer. In this connection the preservation of the specimen is a noteworthy character, as the bone is absolutely intact and the original material unchanged. One might almost suppose it a product of the last half century.

Dr. Chester Stock has identified the specimen from Tomales Bay as belonging to *Mylodon harlani,* a species commonly represented in the Pleistocene of Rancho La Brea.

This form probably occurred in the Tomales formation as the Millerton formation is missing from this portion of Tomales Bay, and the lithological description corresponds to that of the Tomales formation.

The Millerton formation was deposited in a graben along the San Andreas Rift, very similar to the Tomales Bay of the present day. Both the flora and fauna obtained from these beds indicate a climate considerably warmer than that

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[24] Merriam, J. C., Bull. Geol. Soc. America, Vol. II, pp. 612-614, 1899.

which prevails in this region today, an interglacial epoch. The Tomales formation is largely land or stream-laid deposits. During a portion of Tomales-Pleistocene time, however, the region was occupied by a shallow bay. Both its fauna and flora testify conclusively a milder climate for the Tomales epoch.

Undifferentiated Pleistocene

It has been indicated incidentally in the description of the Merced group that marine and stream terraces occur both in the Point Reyes Triangle and the uplifted mainland block. Unfortunately, but little fossil material has been obtained from these terraces of the Point Reyes Triangle. The general profile of the western face indicates unmistakably that the sea was the agent which cut these gigantic steps. Likewise, the even surface which truncates the Merced around Freestone is so broad and level that any other erosion agency except the sea could not have done this planing. Osmont reports some boring mollusks in and around Occidental but the writer was unable to find the locality.

Pleistocene stream gravels were noticed in the Petaluma Quadrangle, three-quarters of a mile southwest of Waugh School, in a road-cut. At this locality a very evident erosional unconformity is present between the Pleistocene gravels and the underlying yellow tuffaceous sandstone of the Merced.

Another interesting stream channel is found in the State Highway a quarter of a mile northwest of Penn Grove. This old stream channel is full of gravel in which large fragments of petrified wood are found. The direction in which the stream flowed in Pleistocene time is apparently at right angles to the drainage of the present day. A similar suggestion of an east-west drainage during upper Pleistocene time was obtained from a study of the stream gravels at Waugh School. From other evidence it appears probable that during a portion of Pleistocene time the streams of this vicinity did actually drain into the streams entering Tomales Bay.

Dr. Chester Stock found interesting mammalian remains in Pleistocene beds one-half mile northwest of the Iowa School. This locality is in the Santa Rosa Quadrangle near its southwest corner, in an area which is largely covered by Merced strata. Dr. Stock has supplied the note given below:

Remains of the ground sloth *Mylodon harlani* were found in the Santa Rosa Quadrangle approximately seven miles northwest of Petaluma and three-quarters of a mile southeast of William McGrew's Ranch house, in bluish clay overlain by gravels of Pleistocene age. These deposits rest unconformably upon greenish-colored sandstones presumably of Franciscan age. The bones were exposed in a gully about 100 yards north of the road leading to the McGrew house and one-half mile west of main road connecting Stony Point with Cherry. The fossil material consists of parts of a pelvis sacrum, and lumbar and caudal vertebræ.

A narrow Pleistocene marine terrace was observed at Dillon's Beach, on the Pacific Ocean between Tomales and Bodega bays, about 50 feet in elevation at its old cliff. This shelf, which is now being rapidly eroded, was cut in micaceous gray Franciscan sandstone, interbedded with thin strata of lignite and carbonaceous shale. The deposits which cover a portion of this wave-cut shelf consist of incoherent tan-colored sandstone, 10 to 30 feet in thickness. The Franciscan rocks in Hog Island are covered by a similar deposit. These last two are probably referable to the Tomales formation.

General impressions obtained very largely from physiographic studies on the tilted mainland block indicate that the time interval required to strip the Merced strata from a considerable area was a long one. This data will be presented again in connection with a discussion of the physiography.

Structure and Stratigraphy

The dominant features of the area under discussion are, as previously pointed out, the Point Reyes Triangle, the San Andreas Rift Zone, the San Francisco-Marin Block, and the Berkeley Hills Block. The Point Reyes Triangle and the orogenic block on the northeast side of Tomales Bay are respectively recognized by Lawson[25] as extensions of the Montara and San Francisco-Marin blocks.

The Berkeley Hills Block which Lawson recognizes in the San Francisco Bay Region, appears in the vicinity of Petaluma and Sonoma Mountain as a dominant orographic feature. Concerning the relationship of the blocks in this area, Lawson, after pointing out the geological differences between

[25] Lawson, A. C., San Francisco Folio, U. S. Geological Survey, p. 15, 1914.

the rocks of the Point Reyes Triangle and those of the San Francisco-Marin Block, states that: "It would therefore seem probable that the earlier movements on this fault zone were pre-Miocene and that they caused a relative upthrow on the southwest side of the fault, in consequence of which the Franciscan rocks were lifted into the zone of erosion and stripped off the underlying granitic rocks. This erosion may have taken place in any part or during the whole of Cretaceous and Eocene time." It must be remembered in this connection that our mapping does not show any Eocene or Cretaceous rocks in this vicinity. Eocene rocks are not found until the vicinity of Carneros Creek in the Napa Quadrangle is reached. Rocks of the Knoxville Cretaceous also occur in this vicinity, so our mapping gives added data in support of Lawson's views.

The occurrence of great thicknesses of Monterey shale in the Point Reyes Triangle and its absence from the San Francisco-Marin Block was recognized as a significant thing by Lawson,* who states: "The shore line of the sea in which these shales were deposited must have lain far east of Bolinas Ridge, for we can not regard the beds at the base of the ridge as in any sense littoral. It follows that the Monterey beds were laid down not only over the area of Point Reyes Peninsula but also over a large part of the territory farther northeast, and that they were therefore spread over the trace of the old fault. In post-Miocene time there was probably a recurrence of movement at the time of the deformation of the Monterey strata, but the effect of this movement can not be satisfactorily differentiated from that of the later post-Pliocene displacement." The indications of the presence of the bituminous shales beneath the Petaluma formation on the west flank of Sonoma Mountain suggest that Lawson's view concerning the distribution of the Monterey is correct. The work in this area under discussion shows that in pre-Pliocene time the San Francisco-Marin Block was uplifted into the zone of active erosion and the northwestern extension of the Berkeley Hills Block which is bounded on the southeast by the Tolay fault was depressed below the base-level of erosion at that time, thus preserving the diatomaceous Monterey shale which in all probability lies beneath the Petaluma lake

*Idem. p. 16.

beds and the tuffs and lavas of Sonoma Mountain. It would appear quite probable that the Point Reyes Triangle was likewise depressed at the end of the Miocene, as it is difficult to account for the preservation of such a great thickness of the Monterey group within such a limited area in any other way.

Movements within the Dominant Blocks

As Anderson indicated in the Geology of the Point Reyes Peninsula, the Monterey strata have been folded in a broad, shallow syncline. The general relations of this structure are shown in the Section E-F which accompanies this report. This folding took place in pre-Merced time, as the Merced probably rests with unconformity upon the Monterey shale at Bolinas Head, near the town of Bolinas, Tamalpais Quadrangle.

The writer did not attempt to work out the structure in the Franciscan rocks but it is probable that the dominant folds which Lawson recognizes in the Tamalpais Quadrangle extend in a northwesterly direction. A fault between the Sonoma group at Grand View and the Franciscan rocks is apparently a movement which did not extend to the northwest as no trace of it was found in Burdell Mountain. This fault, however, may be a dominant structure in its southeasterly extension, but unfortunately a great mass of alluvium prevents us from determining this point. From the general nature of the structure in this part of the Coast Ranges it seems quite probable that movement along this fault at the end of Pliocene time or during the early Pleistocene may have determined the form of Petaluma Valley. The northeastern side of this fault is apparently the downthrown side. However, there are complications within the block, as the basaltic conglomerate near Grand View shows. This basaltic conglomerate extends beneath the alluvium of Petaluma Valley. The State Highway Engineers in charge of building the Grand View bridge, Mr. Gerlach and Mr. Brown, presented the writer with a section which indicates that these gravels are found at a depth of 105 feet at the east pier of the bridge, which is about 400 feet from the Grand View shore line. Minor faulting or folding may have affected the Merced in the vicinity of the Cinnabar School, near the southern edge of the Santa Rosa Quadrangle, as the anomalous dip of 10° S. was recorded here. This, however, is local, as the beds north and south of this locality exhibit little, if any, inclination.

Within the northern extension of the Berkeley Hills block, faulting, with possibly some folding incidental to it, has been very vigorous in the northeastern portion of the Santa Rosa Quadrangle during post-Pliocene time. The writer did not have sufficient time to work out these structures in detail, but certain broad features were recognized. Sonoma Mountain for the major part has not been greatly disturbed by faulting or folding except its northwestern extensions, Taylor Mountain and Bennett Mountain.

Kenwood Valley, a name which the writer proposes for a northwest-southeast valley whose principal town is Kenwood, appears to be a well marked graben, as the Mayacamas Mountains rise abruptly from its northeastern border. These mountains exhibit in some places exceedingly steep dips, as high as 40° to 45° to the southwest. (See Fig. 2, Plate XXV.) The peculiar courses of the streams draining this valley are results of complicated fault movements in this vicinity. Rincon Valley probably has a similar origin. The hills north of Santa Rosa are in detail quite complicated by folding and faulting. The Hayward fault, whose northern extension is recognized on the northwest side of Sonoma Mountain, is in this area as in its type locality, a very recent feature, and it has not greatly modified the structure within the Berkeley Hills block.

During Epi-Miocene time the San Francisco-Marin Block was upthrust, for an erosional surface was developed, upon which the Merced was laid down. Possibly during the upper-Miocene time this block was elevated also, since the Petaluma lake beds lying on the northeast side of Tolay fault indicate that a land mass cut this region from the sea. Since the Petaluma lake beds lie within the northern extension of the Berkeley Hills Block, it appears probable that this block was relatively depressed in upper-Miocene time. During Merced-Pliocene time, the Point Reyes Triangle, an extension of the Montara Block, and the San Francisco-Marin Block were both depressed to receive marine Pliocene sediments and apparently the waters of the Merced sea covered completely, all the region west of the northeastern border of Petaluma and Santa Rosa valleys. Little or no Merced strata occur east of the projection of the Tolay fault in the Petaluma Quadrangle, and it seems probable that the Berkeley Hills Block was somewhat upthrust into the zone of erosion during this time, as much of the lava and volcanic ash deposits of Sonoma Mountain was laid down upon an erosion surface cut across the rocks of the Petaluma formation of upper-Miocene age. During a portion of Pliocene time, a distinct divide cut off Sonoma Mountain and the Berkeley Hills from the ocean, as the Orinda and Siesta formations of the Berkeley Hills are in a large part composed of lacustrine deposits. The Merced-Pliocene was shown to be the equivalent of the Sonoma group and in turn of the Orinda beds of the Berkeley Hills. Within the San Francisco-Marin Block, the uplift during post-Pliocene time was not apparently uniform, as Merced strata are now lacking in the vicinity of Tamalpais. Further north of Tamalpais, in and around Petaluma, residuals of Merced strata occur, and as one goes further northward towards Freestone the thickness increases. Of course it is barely possible that the Tamalpais mass may have been an extension of a Pliocene San Francisco Peninsula, and therefore may not have been the site of Merced deposition. An alternative explanation, that Merced strata once covered Tamalpais but have been removed completely owing to a greater uplift of this portion of the block, is probably correct, as Merced strata once covered its northern flanks. This is clearly shown by the occurrence of Merced beneath the capping of the basalt on Burdell Mountain, which has preserved this small remnant to the present day.

During the Pleistocene the Point Reyes Triangle underwent movements which are not recognized in the San Francisco-Marin Block. This block was apparently successively elevated during this time, with periods of standstill long enough for the sea to chop out a fine series of marine terraces on its western side. These terraces do not have their correlatives on the northeast side of Tomales Bay, showing these orogenic blocks moved independently.

At the beginning of the Pleistocene, the San Francisco-Marin Block was thickly covered by nearly horizontal Merced strata, and at least in the northern portion of this block, excellent evidence that the Pleistocene sea truncated Merced strata, may be seen. As was pointed out above, fine terraces occur around Freestone and to the northwest of this village. After this marine plain (or plains) was formed, the San Francisco-Marin Block was lifted above sea level, consequent Pleistocene streams began their downward and sidewise cutting, and quickly worked through the soft Merced strata to the old erosion surface cut across Franciscan rocks. At this time the drainage was across the block from east to west. Pleistocene Russian River[26] was probably the most vigorous of these streams, as it cut the longest and deepest canyon in the Franciscan. Later in the Pleistocene, the San Francisco-Marin Block was uptilted on its western edge and the lower portions of the consequent streams, with an increased gradient, were enabled to cut canyons in the underlying Franciscan rocks. All the streams on this block which now flow into the Pacific Ocean or Tomales Bay from the Russian River to Elk Creek, have canyons of greater or less length cut into the Franciscan. The tilting variously affected the middle and upper courses of the streams, producing in some cases ponding and in others spilling them out by way of their headwater tributaries, reversing the stream direction.

Topography and Physiography

The principal topographic units of this region, as well as orogenic divisions, are the Point Reyes Peninsula, the Rift Valley of Tomales Bay, the San Francisco-Marin Block which extends from Tomales Bay and the Pacific Ocean, to Petaluma Valley and the northwestern extension of the Berkeley Hills Block, Point Reyes Triangle.

The Point Reyes Triangle, as will be seen by consulting the topographic map of the Geological Survey, has its northeastern base sharply determined by the San Andreas Rift Zone. Point Reyes is the apex opposite this base, and Tomales Point and Bolinas headland are the other apices of

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[26] Holway, R. S., The Russian River, a Characteristic Stream of the California Coast Ranges, Univ. Calif. Publ., Geog. Dept., Vol. 1, No. 1, 1913.

the triangle. The comparatively straight Inverness Ridge parallels the San Andreas Rift. Short, rapid streams descend from the high northeastern scarp of this ridge to Tomales Bay or the Rift Zone in the vicinity of Olema. The southwestern slopes of this ridge are cut by many deeply intrenched streams, which very evidently at one time had far longer courses than is at present indicated, as Drakes Estero is clearly a drowned stream valley, due to the last general subsidence in this region. This southwestern slope of Inverness Ridge has been further chiseled into fine, wave-cut terraces of several different elevations. According to F. M. Anderson the most distinct terraces occur between 600 and 700 feet elevation and at 200 feet elevation. In addition, there are other less distinct shelves, which can be clearly seen from certain points of view. Whether or not these shelves are correlatives with the small plateau near Inverness is exceedingly difficult to decide, since this plateau is so eroded that its exact character was not evident to the writer. Other indistinct plateaus occur in the western shores of Tomales Bay in the vicinity of Tomales Point, but much detailed work would be necessary to decide their origin. Likewise these titan steps in the southwestern side of Inverness Ridge do not have correlatives in the northeastern shores of Tomales Bay in the mainland mass. The Pleistocene beds of the Millerton or Tomales formations which are found in the headlands on the eastern shores of Tomales Bay, are apparently unrelated either to these wave-cut terraces of Point Reyes Peninsula or to the indefinite 400 foot terrace of the mainland mass. This lack of synchrony very clearly indicates that the Point Reyes Triangle has moved upward or downward at times quite independently of the movements of the mainland. The Point Reyes Triangle is then clearly recognized as a definite orographic block whose history is quite different from that of the mainland.

Other differences between these two regions also occur. According to Lawson[27] in the San Francisco Folio:

> The vegetation on the west side of the San Andreas Rift valley is radically different from that on the east side. From Bolinas Lagoon northward, the eastern slope of the main ridge of the Point Reyes Peninsula is covered with a forest which though not continuous, is fairly

[27] Lawson, A. C., San Francisco Folio, U. S. G. S., No. 193, p. 3, 1914.

dense in the areas where it is best developed. This forest is composed almost exclusively of *Pinus muricata*, which is accompanied by a little *Pisania densiflora* and *Quercus agrifolia* and by considerable *Umbellularia californica* on very steep slopes. The densest part of the forest is, however, pure *Pinus muricata*. The shrubs of the Point Reyes Peninsula are northern types, which have here their southernmost or nearly their southernmost representation. These shrubs include *Rubus spectabilis menziesii, Ledum glandulosum* and *Rhododendron californicum*.

The differences in the floras of these two regions are in part due to different soils produced by the contrasting formations, but since the plants on the triangle are northern types it seems probable that actual geographic separation may likewise be a potent cause. The triangle may have been an island during late Pleistocene time and this relict flora may be due to the protection secured by this separation from the mainland mass.

A comparison of the present faunas of these two regions might lead to some interesting results.

THE RIFT VALLEY OF TOMALES BAY

As the geologic map shows, Tomales Bay and the valley of Olema Creek form a very distinct zone separating the mainland mass from that of the Point Reyes Triangle. Tomales Bay is essentially a graben between these two blocks. This graben is not a simple one as the Pleistocene deposits in the northeastern side of the bay show. (See Plate XX; Plate XXXIV, Figures 1 and 2.) The Millerton formation of lower or middle Pleistocene age as is indicated upon the map of this region has been broken into several different wedge-like blocks. Since this region has been carefully studied in relationship to the San Andreas Fault in the Report of the California Earthquake Commission,[28] the reader is referred to this report for further detail.

BERKELEY HILLS BLOCK

The Block described under this heading comprises the northeastern portion of region discussed in this paper. The writer believes that this is a definite orographic block which during the Tertiary has moved as one mass at times, but at other times has been broken into subordinate blocks of notable size.

[28] State Earthquake Commission upon the California Earthquake of April 18, 1906, Carnegie Institution of Washington, Vol. 1, pt. 1, pp. 65-91; pp. 30-35, 1908.

Kenwood Valley

One of the highest points in this Kenwood valley region is Sonoma Mountain, elevation 2465 feet. This mountain mass is separated from the Mayacamas Mountains by a long narrow valley which we will refer to as Kenwood valley. The highest point in this area is Mt. Hood, one of the peaks of the Mayacamas Range with an elevation of 2715 feet. Sonoma Mountain is separated from the northern extension of the Mt. Tamalpais Mountain mass by Petaluma and Santa Rosa valleys. These physiographic units are, in part due to geologic structure, and in part, due to erosion. Only reconnaissance work was done in the Mayacamas Mountains, but the anomalous drainage of this mass is at once apparent from a brief study of the Santa Rosa Quadrangle. A part of the drainage on the southwest side of this range goes into Santa Rosa Creek, a tributary of the Russian River, while the other half reaches the ocean indirectly by way of Sonoma Creek, which empties into San Pablo Bay. The course of Sonoma Creek is particularly anomalous. Sonoma Canyon and its tributary stream, Bear Creek, drain the rugged eastern side of Mt. Hood Ridge, and a northwestern tributary which drains the northwestern side of Mt. Hood Ridge meets the main Sonoma Creek one-half mile northwest of Kenwood village. The main stream, which has been crowded to the southwestern side of Kenwood valley by the alluvial fans of the short, sharp streams descending from the southwestern slope of the Mayacamas Mountain scarp, suddenly abandons what appears to be a perfectly direct course out of the valley, to cut across the hills on the southwest side of Kenwood valley. After flowing in a canyon for two miles due south, the stream then turns and maintains a general southeastern course for two miles until it is joined at the village of Glen Ellen by Calabazas Creek and then proceeds through a narrow valley for a mile to Eldridge. A brief study of the topographic map near Los Guilicos quickly shows that the unnamed western tributary of Sonoma Creek has sometimes swung upon its fan so that the drainage from this slope has been out by way of the small stream draining through Annadel, which for the lack of a better name will be used to designate this odd but significant wet-weather stream. Annadel Creek, flowing in a northwesterly direction, cuts deeply into a low basaltic ridge two miles southeast of Melitta. It is very possible that this stream has followed the course of a fault line as being the easier way, although a comparatively wide, undrained valley one-half mile to the north would seem the logical way. The writer was not able to spend sufficient time upon this interesting problem to work out the details, but it is quite apparent that the canyon course of Sonoma Creek south of Kenwood is clearly antecedent to the fault movements which gave rise to Kenwood valley. Since a northern branch of this stream was well developed before the faulting, this northern branch was able to maintain its course against the upthrust on the southwestern side of Kenwood valley. Likewise Kenwood valley did not drop rapidly enough to divert the drainage out by way of Santa Rosa Creek or north by way of Beltaine Pass, which the Southern Pacific Railroad uses. The northern block, the Mayacamas Mountains, was uplifted with considerable rapidity. The streams draining that block were greatly accelerated and hence could carry a great load of debris which aided in filling Kenwood valley graben. Rincon valley is apparently also due to faulting.

Sonoma Mountain

The main mass of Sonoma Mountain is essentially a lava plateau composed of nearly horizontally bedded basalts and tuffs of the Sonoma group. (See Plate XXX, Figures 1 and 2.) Its northern flanks, Bennett Mountain and Taylor Mountain, have evidently been subjected to considerable faulting at the end of, or during, Pliocene time. Faulting along the Hayward Rift has not affected the main mass of Sonoma Mountain or its principal streams essentially, but minor modifications in the drainage in the southwest flanks in the vicinity of the Petaluma Reservoir and Roger's Creek are results of this recently developed line of weakness. (See Plate XXIX, Figure 1; Plate XXXVI, Figures 1 and 2; Plate XXXVII, Figures 1 and 2.) The drainage of Sonoma Mountain is distributed in three directions: Matanzas Creek and its South Fork, and the south tributaries of Santa Rosa Creek drain the vicinity of Taylor and Bennett mountains. Graham

Creek, Carriger Creek and other small streams are tributary to the master stream, Sonoma Creek, which drains into San Pablo Bay. Roger's Creek is another one of these streams, but through the aid of the Hayward Rift it has succeeded in capturing a portion of the drainage of the southwest side of Sonoma Mountain. The southwest side of Sonoma Mountain is drained in part by Tolay Creek and Petaluma Creek into San Pablo Bay, while the northwestern half of this drainage has an indefinite water parting on the fan of Copeland Creek at Cotati divide. The waters of Copeland Creek and Crane Creek now find their way into Laguna de Santa Rosa, a stream on the western side of Santa Rosa Valley.

Hayward Rift

The northwestern extension of the Hayward Rift is easily recognized on the southwestern slope of Sonoma Mountain, where many characteristic features are seen. The general direction of the rift is, through most of this area, about N. 40° W. in the Santa Rosa Quadrangle, but its general trend as it crosses the northeastern corner of the Petaluma Quadrangle is about N. 20° W. Like the Hayward rift in the Berkeley Hills, this rift is not a simple fault line, but a series of parallel fault lines in a zone which varies from a quarter to a half mile in width. Lawson[29] has shown that the Hayward Rift in the Berkeley Hills is a very recent feature which has only modified the original consequent drainage of the southwestern slope of the Berkeley Hills in a minor way. The same condition is essentially true along the extension of this line in the Petaluma and Santa Rosa Quadrangles. One mile east of the Eureka School on the Sonoma-Petaluma Road three beautiful fault sag ponds were first recognized along a half mile strip in a direction N. 20° W., and the corresponding small blocks which were separated from one another by interspaces, which, like the fault sag ponds, are due to a series of minor differentially dropped blocks. The hills and their interspaces are bounded on their northeast and southwest sides by faults of the Hayward Rift Zone. Such a series of differentially dropped blocks are termed by Law-

[29] Lawson, A. C., San Francisco Folio, No. 193, U. S. Geological Survey, p. 17, 1914.

son, Kernbuts. These peculiar topographic forms were defined by Lawson[30] in his paper upon the Geomorphogeny of the Upper Kern Basin. Lawson's Kern cols, the low passes which the Kernbuts connect with the main mountain mass, are characteristically separated from one another in this region by elongate depressions, the fault sags of Dr. G. K. Gilbert.[31] "Considering the Rift as a physiographic type, I find it convenient to have a specific name for one of its elements, the small valley; and in some of the descriptions which follow I shall speak of it as a fault-sag.

The general relation of the Rift to the greater valley is illustrated by the cross profile in Fig. 7. Along the northeastern side it lies everywhere lower than the adjacent slope of the greater valley, the produced profile of the valley slope passing the fault-ridges (kernbuts of Lawson) as well as the fault-sags. Along the southwestern side some of the fault-ridges appear to project above the restored profile of the greater valley, while the fault-sags lie below. If I interpret the structure correctly, the great compound fault concerned in making the valley includes a certain amount of step faulting which is responsible for some of the western ridges of the rift belt; but with that exception, the ridge and sags of the rift are occasioned by the unequal settling of small crust blocks along a magnified shear zone."

The conditions along the Hayward Rift are essentially the same as Dr. Gilbert has outlined but since this feature is a recent one the topographic forms which are present are on a small scale but were apparently developed "by the unequal settling of small crust blocks along a magnified shear zone." Many of the small hills are elongate-oval in form with major axis parallel to the Rift and the writer is inclined to regard some of them as small "sliver" fault blocks due to minor "scissors" faults along the Rift. The Hayward Rift in this region traverses the long southwestern slope of Sonoma Mountain into which it has cut a shallow trench in basalt. A view from a point a mile southeast of the Petaluma reservoir looking along the rift toward the northwest shows a slightly notched skyline at the end of the Mountain School

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[30] Lawson, A. C., Univ. Calif. Publ., Bull. Dept. Geol., Vol. 3, No. 15, p. 332, 336, 337, 1904.

[31] Report of the State Earthquake Investigation Commission, p. 33, 1908.

road. Three faults occupy the notches and the low ridges are lowered but little if at all, below the former slope of the mountain. (See Fig. 1, Plate XXXVII and Fig. 1, Plate XXXVI and Fig. 1, Plate XXIX.) From these photographs one might gain the impression that the drainage was toward the observer along the Rift, but such is not the case entirely. Only the lower portion of the valley is drained by the headwaters of Rodgers Creek. In the upper portion of the rift valley, the consequent streams still maintain courses across the Rift. Rifting has affected some of their acute-angled tributaries slightly by causing them to join their master streams at right angles and made other minor deflections in their courses. Rodgers Creek, however, drains the lower portion of this rift valley and it has captured the upper portions of the consequent streams which once drained across the rift. This is evidenced by much interesting physiographic detail on the southwest side of the rift in the region one to three miles southeast of Petaluma reservoir. At a point a mile and a quarter southeast of Petaluma reservoir, a wind gap of pronounced character occurs and it is very evident that it was once occupied by a consequent stream to the northeast which is now tributary to the piratical Rodgers Creek. A mile further on, another wind gap was found and in this case a small, youthful tributary of Rodgers Creek is rapidly reversing the drainage to the southwest. A considerable stream once occupied this gap as its relatively wide valley in late maturity is traceable a half mile west. In upper Rodgers Creek typical fault sags are common and in the rift valley a mile and a half southeast of Petaluma two or three elongate hills illustrate the recent fault feature, the kernbut. Near the top of the bordering southwest ridge, on the northeast side, a narrow fault shelf was noted. Fault-sag ponds and kernbuts are seen as one looks to the northwest from the north end of Mountain School road toward Santa Rosa, and the rift evidently extends in this direction along the southwestern face of Bennett Mountain. This feature was not recognized northwest of Santa Rosa unless the sharp line which separates Santa Rosa Valley from the hills north of Santa Rosa town represents a different expression of this line, similar to that of the Hayward Fault, south of Hayward town. The presence of undrained fault-sag ponds, low side-hill fault shelves, wind gaps of small order and minor stream modifications all indicate movements along this line within the last 200 years as many such transient topographic features would have been obliterated within a longer time. No fault furrows or recent fault scars which might be the surface results of movements along this line on April 18, 1906, were found, but the great destruction in the town of Santa Rosa on that fateful day may have been due to subterranean movements along this northern extension of the Hayward Rift.

The physiography of the San Francisco-Marin Block is intimately tied, both to the geologic history of this region previous to the Pleistocene and that very changeful period of the Pleistocene itself. A study of the peculiar type of stream drainage within this block has given the essential clews to the history of this region. Professor Holway's[32] paper upon the Russian River described the Russian River and its tributaries on this block, and his paper upon the Physiographically unfinished Entrances to San Francisco Bay[33] describes the peculiar drainage of Walker Creek and San Antonio Creek, and that of Elk Creek in Sausalito and Tiburon peninsulas. Professor Holway brings out some interesting topographic facts concerning Liberty Gap, which is a few miles northwest of Petaluma, and shows that a general coast depression of 250 feet would cause the sea to invade the Santa Rosa Valley from the west. In this paper he describes the valley of Walker-San Antonio Creek under the name of Lagoon Pass, and indicates that it would be flooded with a similar depression.

The writer will not describe the details of the drainage in this block, as much would be merely a repetition of Professor Holway's excellent work, but will confine his discussion to such additional bits of information derived from a study of this region from a slightly different point of view. The streams draining into Tomales Bay and the Pacific Ocean have certain characteristics in common. From Russian River these streams are, in order, Salmon Creek, Estero Americano, Estero San Antonio, Lagunitas Creek, and one of the small, but interesting streams of the Tamalpais region, Elk Creek. All these streams were flooded a greater or lesser distance

[32] Univ. Calif. Publ. Geog., Vol. 1, No. 1, 1913.
[33] Univ. Calif. Publ., Geog., Vol. 1, No. 3, 1914.

from their mouths as a result of the general subsidence of this region. In most of the streams in the middle portion of the block, wide valley stages are characteristic of their middle courses. Owing to initial differences the streams in the block have been differently affected by the same general movement within the San Francisco-Marin Block during Pleistocene time. Professor Holway concluded that the Lower Russian River was a part of an old stream which existed when the whole region was near sea level, and that Mark West Creek was the direct upstream extension of the Lower River. A glance at the general index map in this publication (See Plate XX) indicates a peculiar condition of Lower Russian River. This portion of the stream is intrenched in Franciscan rocks, but a study of the distribution of the Merced strata in this region and the Pleistocene plain which truncates them near Freestone, indicates that the Pleistocene Russian River attained the essentials of its present course as a consequent East-West stream upon a low coastal plain which was developed upon Merced strata. Merced strata occur at the town of Plantation, a few miles north of Russian River Canyon and at Freestone, only a few miles south of Russian River. The immediate region bordering the Lower Russian River is wholly composed of Franciscan rocks and when one stands upon hills bordering the canyon of Russian River, an old plateau surface is clearly apparent, but this surface is not a perfectly even one and considerable elevations rise above it. The distribution of Merced strata as stated above shows that this old surface was once covered by the muds and sands of a Merced sea. The Pleistocene surface, which is very evident two miles south of the main stream around Freestone (See Plate XXVI) can be traced a few miles north of Freestone to the vicinity of Occidental, where Osmont reports the presence of boring mollusks. To summarize briefly the evidence, a consequent Mark West Russian River of Pleistocene age developed upon a wide low coastal plain. After a slight uplift this stream became intrenched in this plain and since the Merced strata were soft, cut rapidly downward until the old pre-Merced erosion surface which truncated Franciscan rocks was reached. This surface acted as a temporary base level for a time and the stream no longer cut downward but swung from side to side, making a wide valley in the sandstones of the Merced. Later in the Pleistocene, the San Francisco-Marin and the Berkeley Hills blocks were uplifted together and tilted from the west to the east. Since the Mark West Russian River had developed a strong system of tributaries in the mountains northeast of Santa Rosa, its drainage area was the largest of any of the consequent streams within these two blocks. Owing to its greater volume this stream succeeded in maintaining its course against the uptilting of this block during Pleistocene time. Owing to the tilting of this block Santa Rosa Valley became a basin of accumulation and it is the writer's opinion that Laguna de Santa Rosa is ponded as a specific result of the West-East tilt. In other words, there is a neutral zone within this tilted block in which we have a balanced condition as respects drainage.

A part of the story was derived from the study of some of the smaller streams south of Russian River. Salmon Creek has a lower course intrenched in Franciscan rocks, and a middle and upper course which is in a notably wide valley whose surrounding hills are composed of Merced strata and whose valley bottom is underlain at no great depth by rocks of the Franciscan group. A connecting link between the mouth of this stream and its upper and middle course was found about two miles down stream from Bodega town. As one looks across Salmon Creek from this place to the north, well developed stream terraces, a couple of hundred feet above the bottom of the gorge of Salmon Creek are seen. The gorge of Salmon Creek is cut in Franciscan rocks and this stream terrace is likewise composed of Franciscan rocks until its northern boundary is reached, where Merced rocks are encountered at once. This terrace then, is a remnant of a temporary base level, the pre-Merced erosion surface, which was developed upon Franciscan rocks and has been exhumed by Salmon Creek during Pleistocene and Recent times. Salmon Creek was not sufficiently powerful to maintain its course across the entire block. During early Pleistocene time Salmon Creek may have drained the area directly east of Freestone in the vicinity of Sebastopol and Santa Rosa, but the tilting in later Pleistocene time probably diverted the drainage of its eastern headwaters to the east, ponded them somewhat, and they fell an easy prey to the more powerful stream, the Russian River, which succeeded in maintaining a strong course completely across the Berkeley Hills and San Francisco-Marin blocks.

Estero Americano apparently had a similar history. Like Salmon Creek it cut a gorge at its mouth in Franciscan rock. The wide valley stage is seen in the region just east of Valley Ford and in and around Valley Ford the Merced strata rest upon Franciscan rocks exposed in the bottom of the valley. The stream further south, Estero San Antonio and its main tributary, Tomales Creek, exhibit the same characters.

Estero San Antonio and Tomales Creek probably had a drainage that originated in Sonoma Mountain and it is possible that the two old stream channels described under the heading "Undifferentiated Pleistocene" near Waugh School are remnants of this East-West drainage.

When the gorge of Walker Creek is compared to that of Estero San Antonio, one finds that it is far better developed, but its present drainage basin is far less than that of Estero San Antonio. Professor Holway has described the relationship between Walker Creek and San Antonio Creek and has pointed out the ponded area at their present headwaters (See Plate XXIV, Figure 2), and that the present tributaries of San Antonio Creek enter the main stream in certain cases at acute angles whose vertices point toward the source of the stream and not toward its mouth. These anomalous features indicated to Professor Holway that the former course of this drainage was entirely toward the Pacific and that San Antonio Creek of today was in reality the headwaters of a more powerful, ancient Walker Creek. When the Point Reyes and Petaluma quadrangle sheets are placed together Professor Holway's evidence is clearly shown, and if you place a stream line across Chileno Valley and ink the tributaries of San Antonio Creek, the evidence will be even clearer. The writer thinks that the broken backed condition of Pleistocene Walker Creek was, like the changes in other streams previously discussed, due to tilting in late Pleistocene time. That Pleistocene Walker Creek was developed upon a Pleistocene marine plain which graded into a low upland appears probable. That Merced strata once covered the entire valley of the Pleistocene Walker Creek is shown by the small remnant of Merced on the northwest end of Burdell Mountain mass on the south side of San Antonio Creek and the Merced of Spring Hill on the north side of the same stream near its present headwaters. Most of the area south of the Walker-San Antonio Creek valley is now composed of Franciscan rocks and the only suggestion of Merced obtained in this region is the presence of an old erosion surface which appears to rise as one travels from Petaluma southward. This old erosion surface is also seen as one looks eastward from Bolinas Ridge, a mile west from Tocaloma. The physiography of the southern half of the Petaluma Quadrangle was not given detailed study by the writer, but he thinks that this old surface across these ridges indicates that the San Francisco-Marin Block was uplifted higher and given even a greater eastern tilt than the area further north.

A reconnaissance trip southwest on the Point Reyes-Petaluma road which passes through Hick's Valley in the Petaluma Quadrangle and Pomponio Creek yielded some interesting observations. Salmon creek and its tributary, Arroyo Sausal, are cut in solid Franciscan rock, and the tortuous course of these streams when studied upon the combined charts, particularly in the vicinity of Hick's Valley, clearly indicates that they are superimposed streams. Hick's Valley when its bottom is examined is found composed of alluvium which completely surrounds some hills of Franciscan rocks, and this recent material appears peaty in places, thus evidencing a ponding of the upper tributaries of Arroyo Sausal. A low divide separates Hick's Valley drainage from that of Arroyo Nicasio. In the vicinity of the Pacheco School and around Nicasio a similar ponding was observed. At Pacheco School, on a small tributary the ponded condition is still present and marshy ground in a relatively broad valley which is evidently due to recent filling was seen. This tributary and its neighboring tributary as one goes southeast from the schoolhouse are separated by a very low divide and a ponded condition is evident here as well as on the main stream around Nicasio village. As one ascends Nicasio Creek, following up Lucas Valley this ponding disappears and at Big Rock ranch, the stream canyon is in early maturity, as well as Bolinas Creek which heads in this same vicinity. Gallinas and Novata valleys on the bayward slope exhibit the same general characters. Ponding is lacking in both streams and their sidewalls are very steep and meet an alluviated valley due to the last general subsidence in the San Francisco Bay Region very abruptly. It appears probable from these contrasts that Arroyo Sausal and Arroyo Nicasio never had drainage across the entire block during the Pleistocene, but in both cases their upper courses were ponded as an incident of tilting in upper-Pleistocene time.

Looking southeastward from the hilltop about one mile west of Tocaloma, an old plateau surface is visible in the direction of Barnaby Mountain. From the same viewpoint the canyon of Papermill Creek (Lagunitas Creek) appears to be cut in this old plateau and since Middle and Upper Lagunitas Creek (called Papermill Creek in the Petaluma Quadrangle) have a greater drainage area than Arroyo Nicasio, ponding is not so evident along its course. Only a slight suggestion of this effect was noted on its tributary, the San Geronimo Creek, near Mailliard Station.

Elk Creek in Elk Valley of the Sausalito Peninsula has been shown by Professor Holway to exhibit on a small scale essentially the same history of Walker-San Antonio Creek, that is, a Pleistocene stream which once drained the region north and west of Mill Valley Junction in Tiburon Peninsula had its back broken as a result of tilting, and a portion of its waters were spilled out by one of its headwater tributaries.

There is much that the writer has not discovered in the stream drainage of this block, but it appears evident that the tilting of the San Francisco-Marin Block in upper-Pleistocene time, caused similar results in many of the streams of this block, and that these results are not equal because of unequal development of the respective streams.

Petaluma and Santa Rosa valleys were not studied intensively, but the geological mapping of these areas and the physiography of their bounding blocks show that they are not simple synclinal valleys. Faulting may have played a part in their development, at least in a minor way, but another cause may have been effective as well. The marine terrace which was developed during Pleistocene time possibly extended to near the present eastern border of Santa Rosa Valley. When the San Francisco-Marin and Berkeley Hills blocks were given an eastward tilt this eastern border began to receive some drainage from the west. That is, when the backs of Pleistocene Salmon and Tomales creeks were broken, deposition from the west as well as the east began in the ponded area along the former border of an earlier Pleistocene plain.

The velocity of the swift upper portion of Pleistocene Salmon Creek (Santa Rosa Creek) was checked, with the consequent rapid building of great alluvial fans and a southeast tributary of the Pleistocene Russian River, which was strong enough to maintain a course across the uplifted block captured this drainage. The writer is not satisfied that this is a complete explanation, but it is partially correct at least.

Lower Petaluma Valley may have been aided by movements along the fault just southeast of Burdell Mountain, but this valley may have had a history somewhat similar to Santa Rosa Valley as outlined above. A tributary of the Pleistocene Sacramento River captured this drainage and gradually robbed the headwaters of Pleistocene Tomales and Walker creeks. These two valleys are apparently comparatively young, geologically speaking, and developed after the tilting of the mainland block, but before the last event in the Pleistocene, the subsidence which gave rise to San Francisco Bay and the narrow flooded stream valleys of Russian River and its associated streams.

Tertiary Geologic History

Since no Eocene rocks were recognized in this area the events of this period are not well known. Both Martinez, Lower Eocene, and Tejon, Upper Eocene, rocks occur on Carquinez Straits, a few miles southeast, and Tejon rocks are known in the vicinity of Carneros Creek in the Napa Quadrangle east of Petaluma. The nature of some of the sediments in the Martinez indicates that they were deposited upon the outer edge of the continental shelf. The faunas obtained from these beds developed in such a habitat. It appears probable a large portion of the sites of the Petaluma and

Point Reyes quadrangles was once covered by the sediments of the Martinez and Tejon seas, but these were subsequently eroded. Lawson holds that Point Reyes Peninsula may have been under erosion during the Cretaceous and Eocene, as a long time interval would be required to remove the Franciscan rocks from their granite basement. Cretaceous time is quite sufficient for erosion to have accomplished this result.

No Oligocene rocks were discovered in the environs of Petaluma, but rocks of this age are present a few miles east, in a limited area on Carneros Creek, and in the Contra Costa hills. These rocks could have been deposited over the Point Reyes Triangle and the San Francisco-Marin Block and then eroded during Epi-Oligocene time.

As the areal mapping shows, rocks of Monterey Miocene were deposited upon the Point Reyes Triangle, but they are absent from the San Francisco-Marin Block. However, indications of their presence in the Berkeley Hills Block were found. It appears probable that they were removed during Epi-Miocene time from the San Francisco-Marin Block. During this period the Point Reyes Triangle and the Berkeley Hills Block were relatively lower than the San Francisco-Marin Block, faulting being active along the San Andreas Rift and Tolay Fault.

Records of Upper-Miocene time in the Point Reyes Triangle and the San Francisco-Marin Block are completely obliterated, but it appears probable from a study of the Petaluma formation (Upper Miocene) that the San Francisco-Marin Block was uplifted sufficiently high to form a barrier between the ocean and Petaluma Lake, which probably drained out southward into an arm of the San Pablo sea. During Epi-Miocene time both the Berkeley Hills and the San Francisco-Marin blocks were upthrust into the zone of active erosion and an extensive peneplain was developed.

After this long period of vigorous erosion, the two outer blocks were lowered beneath the sea. Sands and muds were deposited unconformably across the older rocks. During this time great lava floods swept downward from the northeast and actually entered the Merced sea. Volcanoes in the same region also threw forth great volumes of ashes which were deposited in the sea and upon the shore, which was located about the present site of Sonoma Mountain. Between these successive eruptions there were time intervals sufficiently long for soils to form from the lavas and for the growth of great forests of pine and redwood. In other portions of the shore during these time intervals, lakes were formed as attested by freshwater cherts, in the Neohipparion beds. In this lake vegetation accumulated in sufficient amount to form a three foot vein of coal. Whether this lake was directly connected with Lake Orinda of the Berkeley Hills region was not determined, but they were, beyond much doubt, synchronous. This is the period during which *Neohipparion gidleyi* and other Pliocene horses flourished in this region.

Great changes took place at the close of the Pliocene. The two outer blocks were lowered and at least the major portions of these blocks were swept at times by the Pleistocene sea. It is very possible that the Point Reyes Triangle was never completely submerged as a Pleistocene Tomales Bay is evidenced by the deposits of the Millerton formation. The immediate environs of Tamalpais were under active wave erosion or sub-aerial erosion during a portion of Pleistocene time as no Merced is now found within this area. Further north, however, the planation effects of the Pleistocene sea across the soft sandstones and shales of the Merced formation are preserved to this day in the vicinity of Freestone. After a marine plain was developed across the San Francisco-Marin Block, the mainland was slightly uplifted. Short, rapid East-West consequent streams developed across this plain. Later, the mainland blocks were tilted and the velocities of the streams in lower courses were sufficiently accelerated, so that practically all cut gorges of greater or lesser lengths at their mouths. Some of the larger consequent streams, such as the Mark West Russian River and, for a time, Pleistocene Walker Creek, maintained courses across the two mainland blocks. Some of the smaller streams, however, were quickly ponded in their middle courses as a result of this tilting and were early spilled out to the east by way of their head-water tributaries.

That marked climatic changes took place in the San Francisco Bay Region as well as in the Sierra Nevada is shown by two distinct faunas and floras of Pleistocene age. Both the Millerton and Tomales faunas and floras indicate a climate like that of San Diego at the present day. Elsewhere in the Bay Region, as on the Santa Cruz coast, the fauna obtained from one of the marine terraces flourished under conditions similar to that of today. In brief, glacial and interglacial epochs appear to be registered by the marine sequence on the Pacific Coast.

The entire region under discussion was affected by a last general subsidence which gave rise to San Francisco Bay. Drake's Estero and other drowned valleys of all of the streams, as well as the graben of Tomales Bay, evidence this clearly.

Appendix: Economic Notes

Manganese and Chrome Deposits

From time to time various reports of the State Mining Bureau have mentioned the occurrence of Manganese ores and Chrome-iron within this area. One of the Manganese localities is on what was formerly known as the Mailliard Ranch. The Manganese ore occurs five-eights to six-eights of a mile south, 45° west, of Mailliard Ranch-house, near Mailliard Station, on the east side of a small stream which is tributary to San Geronimo Creek, in connection with an outcrop of radiolarian chert. Analyses of samples from this locality indicate that the deposit is too siliceous to work economically under present conditions. Chrome-iron ore was also reported from this same vicinity, but no deposit has ever been located. The samples obtained were float specimens found within the serpentine areas of this region.

Limestones

No workable deposits of limestone suitable for the making of quick-lime were discovered, but a limestone within the Franciscan rocks, which may be suitable as a fertilizer for sour soils, was examined. Mr. Donald G. Martin, assistant farm advisor of Sonoma County, accompanied the writer to this locality, which is three miles south, 20° west, of Petaluma town, in the northwest quarter of Section 16, Township 4 north, 7 west, Mt. Diablo Baseline and Meridian. This locality is on the western spur of a hill, whose elevation is 296 feet. The limestone outcrop occurs at an elevation of 400 feet, which point is near the west line of the section, about 150 feet above the wagon road which cuts the northwestern corner of Section 16. The exposure is about a hundred yards long and 35 to 40 feet in width. There is a three-foot stratum of limy conglomerate in the middle of the section. A small amount of development work had been done on the exposure when the writer visited it on May 18, 1918, and it seems entirely probable that the deposit will yield a tonnage sufficiently large to warrant exploitation. The hills to the north across the valley were carefully examined, but the outcrop does not extend in that direction. The hill to the east was also examined, but no outcrop was discovered. The northern end of the deposit stops quite abruptly and the writer is inclined to think that a cross-fault may terminate the deposition to north. The southerly extension of this deposit disappears gradually as one descends the hill slope. A cross-cut should be made at the southern end to determine whether this gradual disappearance is due to a lense structure or merely to a thickening of the soil cover at that place.

Another deposit occurs on the Jacobsen ranch, near the southeast corner of the northwest quarter of Section 9. An old limekiln at this place, long abandoned, shows that this deposit was opened years ago. The limestone at this place is too gravelly to be of value even as a source of ground limestone. Another small deposit occurs in Section 17 on the west side of the Point Reyes-Petaluma-Red Hill road, but the deposit is cut off by serpentine and schist and has apparently been intruded by the serpentine. The deposit is too small to be economic. All of these occurrences of limestone are closely associated with typical cherts and schists of the Franciscan group, and the writer has assigned them to it on this account. The limestone deposit in Section 16 is an unusual type of rock in that it is associated with conglomerate and appears to be a beach deposit. Certain obscure markings in this limestone suggest that it is composed of comminuted shell fragments. The deposit should be carefully searched for fossils.

Clays and Coal

Workable deposits of clays suitable for brick-making or tile are common in the outcrops of the Petaluma formation, near Eureka School. Excellent exposures of these clays occur in an eastern branch of Tolay Creek, a mile and a half south, 30° east, of Eureka School, and in the creek a mile and a half east of Adobe Fort. Other exposures within this same formation occur in the lower slopes of Sonoma Mountain. These deposits are located sufficiently close to roads and railroads to receive economic consideration. As the Santa Rosa Quadrangle shows, this region is the type locality of the "basalt block," as abandoned quarries occur in large numbers throughout the Santa Rosa and Petaluma quadrangles. These quarries were abandoned owing to the increasing use of concrete and asphaltic concrete roads. Many excellent basaltic outcrops have been exposed through these abandoned workings. Some coal seams occur in the Neohipparion gidleyi beds of the Sonoma group on its western face, but these deposits have not proved economic, although Mrs. Thompson reports that the coal obtained from the prospect at Lawlor's ranch was of excellent quality. Samples of coals and clays were collected from the western side of Bennett Mountain by Mr. W. W. Watts of the California State Mining Bureau, several years ago. These old workings are now closed, but the writer doubts their economic value.

Oil

The bituminous sandstones as reported in the Sonoma group indicates the probable occurrence of Monterey shale beneath the basalts and tuffs of the Sonoma group and the sands and clays of the Petaluma formation. Whether oil might be obtained in this region is problematical. The writer however, is not inclined to condemn this area entirely, and it may warrant exploitation in the future. The possible area which might be exploited is essentially the region in which the shales and sandstones of the Petaluma formation are mapped. This possible oil region might be widened slightly on the northeast, but the Tolay fault definitely limits the possibilities of this region on the southwest side. This is nicely shown in the geological cross-section along the line C-D, Petaluma and Santa Rosa quadrangles. As explained above, it is the writer's opinion that the Monterey formation, which is probably beneath the Petaluma formation in this region, was preserved from erosion by being dropped below base-level along the Tolay fault at the end of the Miocene or during Epi-Miocene time. As will be seen from the geological map, the structures within the Petaluma formation are, as a rule, small, and exploitation for oil in this region would be attended with considerable expense. The best location is the anticline north of the Eureka School along the road between the Eureka School and Adobe Fort.

Water Resources

ARTESIAN

The synclinal structure at the head of Tolay Creek is a fold in the Petaluma formation and it appears quite possible that moderately deep wells sunk in this syncline might obtain water, since this formation has abundant coarse sandstones to act as water reservoirs, and good stiff impervious clays overlying these sandstones, acting as a cap rock. It is possible that water might be obtained from the same synclines about two miles northwest of Adobe Fort in the Santa Rosa Quadrangle. The possibilities for artesian water in the Petaluma Quadrangle are very slight, as most of this region is underlain at no great depth by the non-water-bearing rocks of the Franciscan group. This group has been tested in many places within the Santa Rosa Quadrangle and practically all the wells sunk are failures. The same statement applies to the southwestern corner of the Santa Rosa Quadrangle and most of the Point Reyes Quadrangle as well. Suitable structures in Sonoma and the Mayacamas Mountains were not recognized. Time did not permit a thorough exploration of the artesian possibilities of Santa Rosa Valley.

GROUND

One of the interesting results of the investigation of the Merced deposits around Petaluma was the recognition of the intimate relations between ground-water and the unconsolidated sandstone of this Merced group. The Merced sandstones in and around Petaluma vary from 50 to 200 feet in thickness and rest upon the relatively impervious rocks of the Franciscan group. The pore space in these sandstones is large and hence much water can be reservoired within them. If it were not for this fact the numerous small chicken ranches around Petaluma on the north and west, as well as around Penn Grove, would be failures, owing to the lack of water. Nearly all these places have shallow wells sunk in the Merced sandstone and can obtain a moderate but independent supply of water. The light sandy soil yielded by the Merced is warmed readily by the spring sun and, with aid of fertilizer, produces fair yields of green crops necessary for the fowls. A third factor in making Petaluma a poultry center is due to cheap transportation provided by small river steamers which navigate Petaluma Creek, a stream drowned by the subsidence of the Bay Region.

The ground-water relations of the Merced are splendidly exemplified in Spring Hill, a half mile west of Marin School, about three miles west of Petaluma town. (See Geological Cross-section along the line A-B, Petaluma and Santa Rosa Quadrangles.) As will be seen from this section the deposits of Merced rest upon basalt, which in turn rests upon Franciscan rocks. This relationship is nicely shown in Plate XXVIII, Figure 1. The Merced sandstone resting upon this basaltic flow is from 50 to 100 feet in thickness, and all around Spring Hill at the contact between the Merced and the basalt numerous springs occur. The dwellers on Spring Hill are thus favored by Nature, who, not satisfied with the impervious Franciscan beds, laid down upon them an excellent grouting of hard basalt, 50 to 100 feet in thickness, and then the waves of the Pliocene sea deposited coarse grained Merced sands, thus providing a sponge-like mass for the favored residents of this beautiful hill country. The dwellers within Franciscan areas in this region must be content with obtaining a small water supply from the shallow alluvium of small valleys, or pipe it from Sonoma Mountain.

The city of Petaluma has its water reservoir on the southwestern slope of Sonoma Mountain in the Santa Rosa Quadrangle, directly within the Hayward Rift. Although the writer did not verify this condition, it seems probable they have enlarged and modified one of the fault-sag ponds along this rift by damming its southeast side. This rift, like the San Andreas Rift, lends itself particularly well for reservoir sites, as it crosses the normal courses of the streams on the mountain slopes and makes their diversion an easy and natural one along its trend. At the same time the city of Petaluma should provide an adequate secondary reservoir as insurance against earthquake movement along this zone of recent seismic activities.

Explanation of Plates

PLATE XIX

The sketch model of the Central Coast Ranges of California represented upon this plate is thought to be correct to the extent of giving a reasonably accurate impression of the general features of the central coast region of California. No reliable topographic maps exist for the major portion of the area shown. The exact elevation of the mountains of the extreme northern portion is known in relatively few instances; elevations south of the Golden Gate are fairly accurate. From photograph by Professor R. S. Holway, Geography Department, Univ. of Calif.

PLATE XX

Photograph of sketch model and index map of San Francisco Bay Region and the Russian River, prepared under the direction of Professor R. S. Holway, Geography Department, Univ. of California. This picture was kindly loaned by Professor Holway.

PLATE XXI

Figure 1. View from Tomales-Dillon's Beach road about two miles west of Tomales, looking northwest, showing Merced sandstone in the foreground and marine plain on the sky-line. Elevation about 500 feet.

Figure 2. View from Tomales-Dillon's Beach road about two miles west of Tomales looking west, showing Tomales Point and the entrance to Tomales Bay. The small hill, Tom's Point, surrounded by water near the extreme left of the picture is composed of Pleistocene beds which dip to the east about ten degrees.

PLATE XXII

Figure 1. View from a hill about two miles west of Tomales showing east end of tilted marine plain, looking northeast toward Santa Rosa. This plain is cut in Merced Pliocene rocks. Franciscan rocks are exposed in deeper stream canyons which are incised in this plain.

Figure 2. View from Tomales-Dillon's Beach road looking west, about one and three-quarter miles west of Tomales showing coarse conglomeratic Merced sandstone dipping about 10°-15° to the northeast.

PLATE XXIII

Figure 1. View of Pleistocene terrace opposite Inverness Yacht Club. The Tomales formation rests with marked unconformity upon the Millerton formation in this headland.

Figure 2. View of Tomales Bay looking northwest. Tom's Point in the distance, Tomales Point beyond. On the right is a small terrace covered by the Tomales formation.

PLATE XXIV

Figure 1. View from the west flanks of Sonoma Mountain, Lawler Ranch: Tuffs and basalt (?) in foreground; Petaluma lake beds which yielded Corbicula californica in the middle ground; Petaluma and Petaluma Valley in the background. The even sky line in part represents a marine terrace on right of picture.

Figure 2. View of Walker and San Antonio Creek divides, about five miles southwest of Petaluma showing the present divide between these two streams. The Merced formation covers the divide one mile northeast of the viewpoint of the picture. The rocks composing the hills shown in this view are all Franciscan, but the valley of the Pleistocene San Antonio Creek, which once drained to Tomales Bay was determined upon a Pleistocene marine terrace in the incoherent sandstone of the Merced formation.

PLATE XXV

Figure 1. View looking north from divide fan about three miles west of Kenwood. Mt. Hood, which is not shown, is to the right of this view.

Figure 2. General view from divide fan three miles northwest of Kenwood, showing Mt. Hood and a sharp peak on the south flanks of this mountain. This peak is due to steeply dipping tuff-breccia beds.

PLATE XXVI

Figure 1. Looking across Salmon Creek, three-fourths of a mile southwest of Freestone. Note horizontal Merced strata. Franciscan rocks occur in creek bed and by barn a quarter of a mile up stream.

Figure 2. Looking northeast from Freestone across Salmon Creek. Fair fossil collecting in creek bed on left of picture. Sonoma tuff stratum is exposed near the top of the hill in the middle of the picture.

PLATE XXVII

Figure 1. View looking northwest across the mouth of Walker Creek. Merced strata caps the hills on the sky-line, but Walker Creek Canyon is cut chiefly in Franciscan rocks.

Figure 2. View of Tomales Town, which is located upon a small tributary of Walker Creek, Keys Creek, which has not yet succeeded in cutting into the hard Franciscan rocks and its relatively wide, shallow, valley is determined by the old erosion surface of pre-Merced age. The hills behind Tomales Church are composed of Merced strata.

PLATE XXVIII

Figure 1. Basalt in foreground; Merced cap on top of Spring Hill, three-quarters of a mile west of Marin School, Petaluma Quadrangle. The basalt in turn rests upon Franciscan rocks.
Figure 2. Tuffaceous Merced resting on basalt, corner Stanley and Howard Sts., Petaluma.

PLATE XXIX

Figure 1. View looking southeast along the Hayward fault line from highest point in road about one and one-half miles northwest of Petaluma reservoir. Fault sag pond in the middle ground. Petaluma reservoir in distance.
Figure 2. Flanks of Sonoma Mountain. Plateau determined by hard, resistant tuff-breccia and lava flows overlain by softer shales and sandstones of the Neohipparion beds of Lawler Ranch, a quarter of a mile away.

PLATE XXX

Figure 1. Sonoma mountain top; a lava plateau.
Figure 2. Looking southwest across the top of Sonoma Mountain.

PLATE XXXI

Figure 1. Petrified forest, five miles from Calistoga. View showing "queen of the forest," a petrified redwood tree, which was once almost entirely covered by volcanic tuff.
Figure 2. A smaller, but more nearly perfect specimen, showing the nature of occurrence in this interesting fossil forest. The tree in figure 1, the tree here figured, and the other trees which have been excavated all lie in the same general direction, tops toward the southwest, and roots of the trees upturned toward the northeast, thus indicating the direction from which the tuff-breccia mud flow which engulfed these trees came.

PLATE XXXII

Figure 1. A view looking southwest toward the head of Tomales Bay, Hog Island, center. A fault sag pond occurs in the middle ground about twenty-five feet above sea level.
Figure 2. View looking north from Dillon's Beach, showing a small remnant of Pleistocene Terrace.

PLATE XXXIII

Figure 1. Unconformity between Tomales and Millerton formations, one and three-quarters miles northwest of Millerton.
Figure 2. View showing unconformity between Millerton and Tomales Pleistocene formations, one and three-quarters miles northwest of Millerton. Upper clays are horizontal.

PLATE XXXIV

Figure 1. Rifted Pleistocene shale, northwest side of Tom's Point.

Figure 2. Pleistocene shale on northwest side of Tom's Point, east of figure 1. The beds which are dipping away from the observer to the northeast are also cut by another fault along the San Andreas Rift.

PLATE XXXV

Figure 1. Pleistocene shale resting on conglomerate, one and three-quarters miles northwest of Millerton.

Figure 2. Pleistocene shale and conglomerate at west end of headland, one and three-quarters miles northwest of Millerton.

PLATE XXXVI

Figure 1. Triplicate Rift Lines. View from one and one-half miles southeast of Petaluma Reservoir looking northwest. A fault shelf is seen in lower right, a kernbut in center and a notched sky-line marking the three lines of rifting in the background.

Figure 2. Looking southeast along the Haywood Fault line two miles from Petaluma Reservoir; rift zone is marked by three lines, two of which are indicated by a kernbut, a wooded hill in the right center of the picture.

PLATE XXXVII

Figure 1. Sonoma Mountain, Hayward Fault. Looking northwest from a point one mile southeast of the Petaluma reservoir. Note the kernbut in the sky-line. The Petaluma reservoir is located in the distance just above the heavy woods. A fault scarp appears in the middle ground and a long narrow kernbut is seen west of this scarp. Faulting in this region is marked by two and sometimes three rift lines.

Figure 2. Looking southeast along the Hayward Fault line two eighth of a mile southeast of Petaluma Reservoir. The Hayward rift beheaded the stream once draining across the surface, and its drainage is now southwest by way of Rodger's Creek.